

Reprint. "The Need of a National Laboratory for the Solution of River Problems" Aug. 1923

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THE NEED OF A NATIONAL HYDRAULIC  
LABORATORY FOR THE SOLUTION  
OF RIVER PROBLEMS

BY

JOHN R. FREEMAN, Past-President, Am. Soc. C. E.

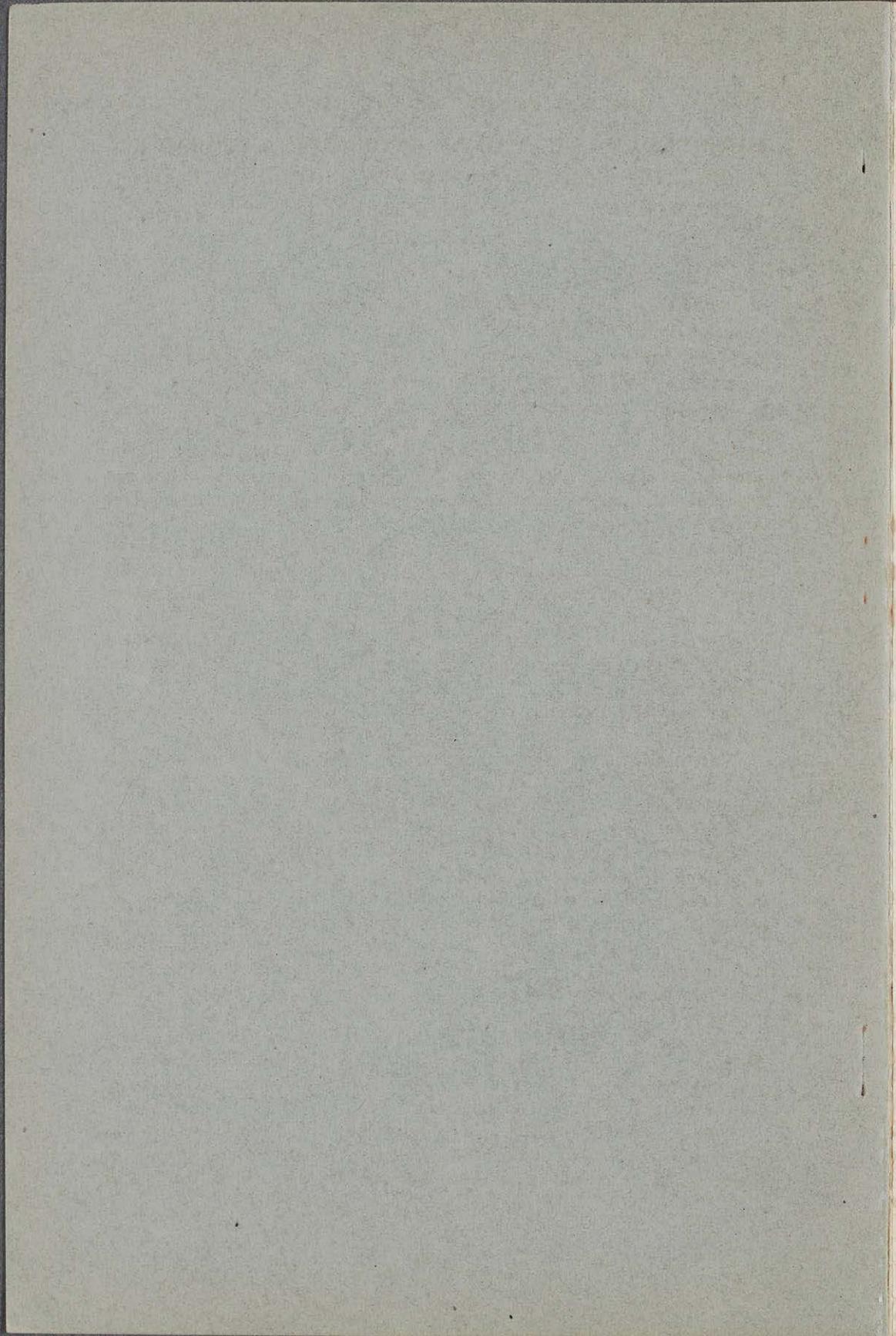
WITH DISCUSSION BY

MESSRS. B. F. GROAT, HARDY CROSS, L. W. WALLACE, L. K. SHERMAN,  
MORRIS KNOWLES, GARDNER S. WILLIAMS, A. W. NEWTON,  
JOHN MILLIS AND C. E. GRUNSKY.

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## THE NEED OF A NATIONAL HYDRAULIC LABORATORY FOR THE SOLUTION OF RIVER PROBLEMS, ETC.

BY JOHN R. FREEMAN,\* PAST-PRESIDENT, AM. SOC. C. E.

### INTRODUCTION

Two of the great problems of the Mississippi Valley are:

- (1) Relief from floods; and
- (2) The creation of a navigation route by which the products of its farms and mines can be transported cheaply to the sea.

The Federal Government and the States have expended hundreds of millions of dollars in trying to solve these problems; but it is still possible for one break in a levee to lay waste 5 000 sq. miles of as fertile land as the sun shines on, with a loss of \$25 000 000 almost over night; and navigation in any important sense above Vicksburg, Miss., appears to be dead beyond present prospects of resurrection.

One who has seen this mighty river tearing along in flood, 1 mile wide and 100 ft. deep, within a few inches of the top of the levee, may well wonder how the problem of resisting its angry force can be taken into a laboratory, or what can be done in a laboratory about disposing of the 1 000 000 000 cu. ft. of earth per year now tumbled into its swirling waters, shifting its strangely crooked course, and obstructing the navigation channels with shoals and snags from fallen trees.

We think of a laboratory as the place of microscopes, of delicate balances and test tubes, and far removed from giant drag-lines and dredges.

What hope is there from an appropriation of only \$200 000, suggested in the pending bill for a laboratory, when for more than twenty-five years appropriations in terms of millions have failed to bring relief?

From St. Louis, Mo., to the sea, the river travels 1 240 miles, and its flood level goes down a slope of 400 ft. It is the most crooked big river in the world. In places it travels about 200 miles to make 100 miles of progress. If its path were straight, all this water could be carried more quickly with half this fall, and as it is a long way down to bed-rock through delta mud, if this channel could be made straight and its banks kept from caving, the flood surface could be lowered below the level of the deepest swamps, and there could be half a dozen reproductions of the Keokuk lock and power development scattered along its course, with a channel deep enough to take an ocean liner to St. Louis.

The river has 1 000 miles of concave bends with caving banks, and history shows that every short cut made across the neck of a bend has led to years of trouble for the river engineer, by tearing down more banks and depositing more of the bars that obstruct navigation.

After 40 years of invention and diligent trial, the only way yet found to hold the river bank from caving is by a mattress of willow trees, or of concrete blocks, which, at present prices, costs \$300 000 per mile, and at the rate of

\* Cons. Hydr. Engr., Providence, R. I.

progress for the past 20 years would require more than 200 years and more than \$200 000 000 to complete the job of using revetment mattresses to prevent banks from caving.

The engineers employed along the river and the people living there must not regard us from the North as trespassers on their preserves when we are drawn to look into these matters, for the whole country suffers from lack of progress and helps to pay the bill, and they must not forget that working with or against these great forces of Nature has a fascination that draws attention from engineers living far outside the valley.

The speaker believes that the future is full of hope; that it is within economic reach to solve these two great problems of flood protection and navigation, but that it may take another 43 or 73 years to find out just how, and to finish the job. It is 43 years since the Mississippi River Commission was appointed, and 73 years since Humphreys and Abbot began their scientific studies of the physics and hydraulics of the Mississippi.

The kind of hydraulic laboratory proposed should be explained because, according to the schedule compiled in 1922 by Engineering Foundation, there are now about fifty hydraulic laboratories of one kind and another in the United States, most of them at technical colleges, and most of them small. Among them all there is not one of the kind now proposed; not one that is suitably designed for studying the problems of erosion and sedimentation in river banks and beds, and the means by which the banks can be protected against erosion. In Europe, however, river-training laboratories have been in operation for more than 20 years.

The thousand miles of caving river banks, 40 to 100 ft. high, the digging of channels 100 ft. deep, the erosion, the transportation of sediment at the rate of 1 000 000 000 cu. yd. per year, the building up of obstructions to navigation by the mighty forces of the great river, after all, may be found chiefly dependent on little things. Among the earliest fundamental problems for the proposed laboratory are those of the detachment of particles of gravel, sand, and even microscopic colloidal silt from their bed by impact of a current of water, the suspension and transportation of these particles in the moving current, and the conditions of current under which such particles cease to move. There is also the important problem of the precipitation (by the admixture of salt water) of the extremely minute particles of silt in suspension and the further development of Stokes' law, and perhaps some very important developments of molecular physics, surface tension adsorption, etc., which may have much to do with saturation, angles of repose, and the stability of river banks. The speaker has not found a reference to the effect of the undercurrent of salt water on the precipitation of Mississippi silt. Possibly it has much to do with this. He has found evidence of a large proportion of colloidal material in a sample of silt recently dredged from the Mississippi. Study in colloidal physics may aid in explaining the "mud lumps" at the river's mouth, and the obstruction of the passes.

When the distinguished geological physicist, the late Grove Karl Gilbert, was called to assist the California River Débris Commission, one of his first

works was to compile all that he could find of laboratory research on these matters and, finding far too little, he next established a small laboratory in which a valuable beginning was made; but his facilities were limited, and his results stopped far short of what is needed at the very foundation for success in river training. Prior to his work, most of the textbooks were quoting as authority the petty experiments of Dubuat, made about a hundred years before, which lead mostly to erroneous conclusions.

After these fundamental physical laws and conditions become better understood, the work of the laboratory can be turned to larger things.

#### PRACTICAL PROBLEMS AND PROSPECTS

Foremost among the practical problems for the laboratory are those of finding the most economical forms of structures for protecting river beds and river banks from erosion, more quickly built and less expensive than the present standard mattress of fascines or concrete slabs. Studies in the laboratory should supplement the field experiments on types that heretofore have failed, such as rip-rap, spur-dikes, gabions, "bank-heads," permeable "hurdles" and abbatis or "retards" and, most important of all, means must be found for permanent anchorage of such structures over a bed of shifting sand.

There are also problems of the limiting radius of curvature of banks or groyne for avoiding destructive eddies around and below their ends; and there are problems of the best forms of structure for inducing the muddy current to fill up an area by the deposit of silt.

There is also great need of making further trials on models in the laboratory, at relatively small expense, on variants of such structures as were partly developed by experiment in the field on full-size specimens. The United States Government 40 years ago expended millions of dollars and years of time in field experiments on permeable dikes and structures for narrowing the Mississippi and Missouri Rivers to a uniform channel width, so that they should scour suitable depths for navigation over the sand-bars, but found these field experiments so costly that apparently Congress and the Commissions have become discouraged and appear to have abandoned the attempts at narrowing the wide places, where the sand-bars form, and for 40 years past have expended most of their appropriations on the revetment of caving banks. More than \$2 000 000 was spent in experimental work on forms of permeable dikes, etc., for guiding currents in the Plum Point Reach of the Mississippi in 1882 to 1885, most of which, as structures, were dismal failures; although extremely valuable data were obtained and proof was found that the river would quickly build up a bank nearly to highest flood level if only a durable form of spur dike or "retard" could be devised. This money was far from being all wasted if one puts proper value on the information obtained.

Millions of dollars also have been spent on the Missouri River with encouraging results as to depth produced, but apparently without yet finding a durable form of spur dike that will not soon be sunk by under-scour, or have its head ripped off by ice or floating snags.

There seem to have been many encouraging results in these field experiments by the Army engineers. Some of these are noted by J. L. Van Ornum,\* M. Am. Soc. C. E., particularly those at Horsetail Bar, below St. Louis, formerly one of the worst places on the river, and it seems a pity not to continue with the laboratory to help point the way to economy and final success.

A week's work with a model, in which changes of shape and position can be readily made, at a total cost of a few hundred dollars, may tell more than 6 months' time and \$10 000 spent on an experimental dike or groyne in the field. Coefficients of the relation between model and full-size original will soon be established, and, after the variants have been tested on the model, one can go ahead with great confidence in the field.

The experiments by Froude, on towing ship models in the long laboratory tank, were at the very foundation of progress in the design of naval and merchant vessels, and it is entirely within reason that similar improvements in the art of training rivers to maintain navigable channels without frequent expensive dredging, and in making them carry their floods to the sea more safely and quickly, may come from the proposed laboratory.

After reading studiously what can be found in print about all this experimental work, with permeable barriers and spurs, by the Army engineers at Plum Point, 90 miles above Memphis, Tenn., and the successful work on the Missouri near Jefferson City, Mo., and after observations in many places, the speaker is not convinced that the improvement contemplated by the late James B. Eads, F. Am. Soc. C. E., and his associates, in the early days of the Mississippi River Commission, of narrowing the wide parts of the river so that it will dig and maintain its own channel to a minimum depth of 10 ft., is impossible or beyond economic reach. On the contrary, he is very hopeful that, proceeding step by step, with the aid of the laboratory to point the way to new devices in the field, and by developing methods and structures gradually, first on the smaller rivers, Platte, Missouri, Sacramento, and Colorado, progress, within another 40 years or less, can possibly attain at relatively small cost to the much desired 14-ft. channel from St. Louis to the sea, which the Commission of 1908 estimated to cost \$128 600 000 at the low unit prices of those days, with upkeep at a cost of \$6 500 000 per year.

It is also within reasonable, but very distant, hope that ways may be found, within economic limits, for compelling the Mississippi to dig its bed so much deeper that the flood-plain from St. Louis or Cairo to Vicksburg may be lowered below the level of the bottom-land, and levees be no longer needed.

The speaker is convinced that these two final objectives, the navigable river and the lowered flood-plain, are far from being iridescent dreams or pots of gold at the end of a rainbow.

As showing the wide margin, far beyond the actual needs for this channel depth and in fall in river slope, it may be recalled that to-day the average low-water depth between St. Louis and Vicksburg is about 35 ft. at extreme low water; that the shallows occupy hardly one-twentieth part of the distance; that

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\* "The Regulation of Rivers".

the length of river with all its present bends and meanders—868 miles from St. Louis to Natchez, Miss., to go about 515 miles in a straight line—and that the lessened friction on a straight course added to the saving of fall by the shortened distance, would save nearly one-half the drop of 379 ft. that now exists between St. Louis and New Orleans, La., which half is about six times the drop at the great water-power development and navigation lock at Keokuk, Iowa; and that the only place yet found where bed-rock is not far below the present bed of sand or mud, is in a relatively short stretch near Commerce, Mo.; where one might picture a second Keokuk development.

Surely here is ground for hope that our grand-children can utilize a part of these opportunities in a shortened and deepened course for gaining the increased navigation and the relief from flood.

#### OTHER HYDRAULIC DATA NEEDED

Apart from river-training problems, engineers need more accurate formulas for computing the discharge over dams, for which the chief dependence is now placed on the Francis experiments at Lowell, Mass., made 60 years ago, in which the maximum depth was only a little more than 2 ft. Also, there is important lack of data on the discharge of drowned weirs, of siphon spillways, on the possibilities of "Venturi flumes" and great need of experimental development by models of baffle-piers and water cushions for absorbing the destructive energy at the foot of a dam, that sometimes undermines foundations, as at those which failed at Austin, Tex., and Austin, Pa. There is also need of tests and new devices for increasing the precision of measurement of flow of water in irrigation and power canal, particularly where there are spiral or diagonal currents.

In a hundred such matters, the few pieces of apparatus proposed to complete this laboratory could serve the progress of engineering, just as the great testing machines and other pieces of apparatus at the U. S. Bureau of Standards or the U. S. Bureau of Highways, serve the public good in other important matters.

Some illustrations are presented in order to show more definitely the kind of laboratory proposed.

#### DESCRIPTION OF PROPOSED LABORATORY

Fig. 17 shows the river flume on one side of the building and the weir flume on the other. Both are fed from the same pumps, forebay, and supply basin, and both discharge into the same measuring basin. Both flumes utilize the same return channels and Venturi meters, as shown in Fig. 18.

The discharge can be measured with extreme precision throughout a wide range. These precise measurements are to be made in a large rectangular basin, thus obtaining them directly in terms of the cubic foot and the second, without recourse to any intermediate measuring device.

Nevertheless, Venturi meters, with various sizes of throat adapted to different rates of discharge (commonly used only one at a time), are provided for hastening the completion of all ordinary experiments, thus requiring fewer men in the observing staff by providing continuous measurement, by

using a clock-gauge, without recourse to the swinging gate and the measuring basin. The measuring basin, of course, serves to give a particularly precise rating for each of these Venturi meters.

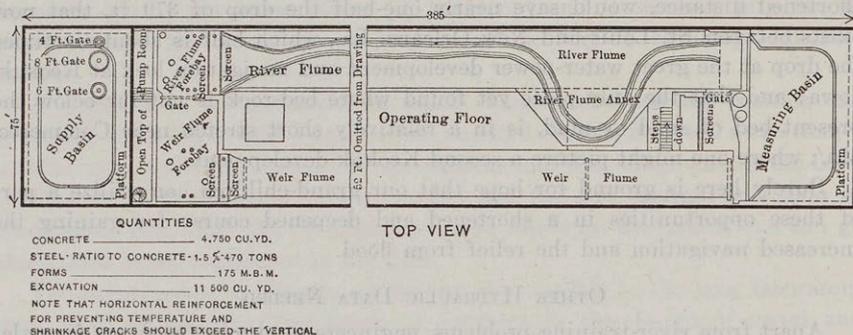


FIG. 17.

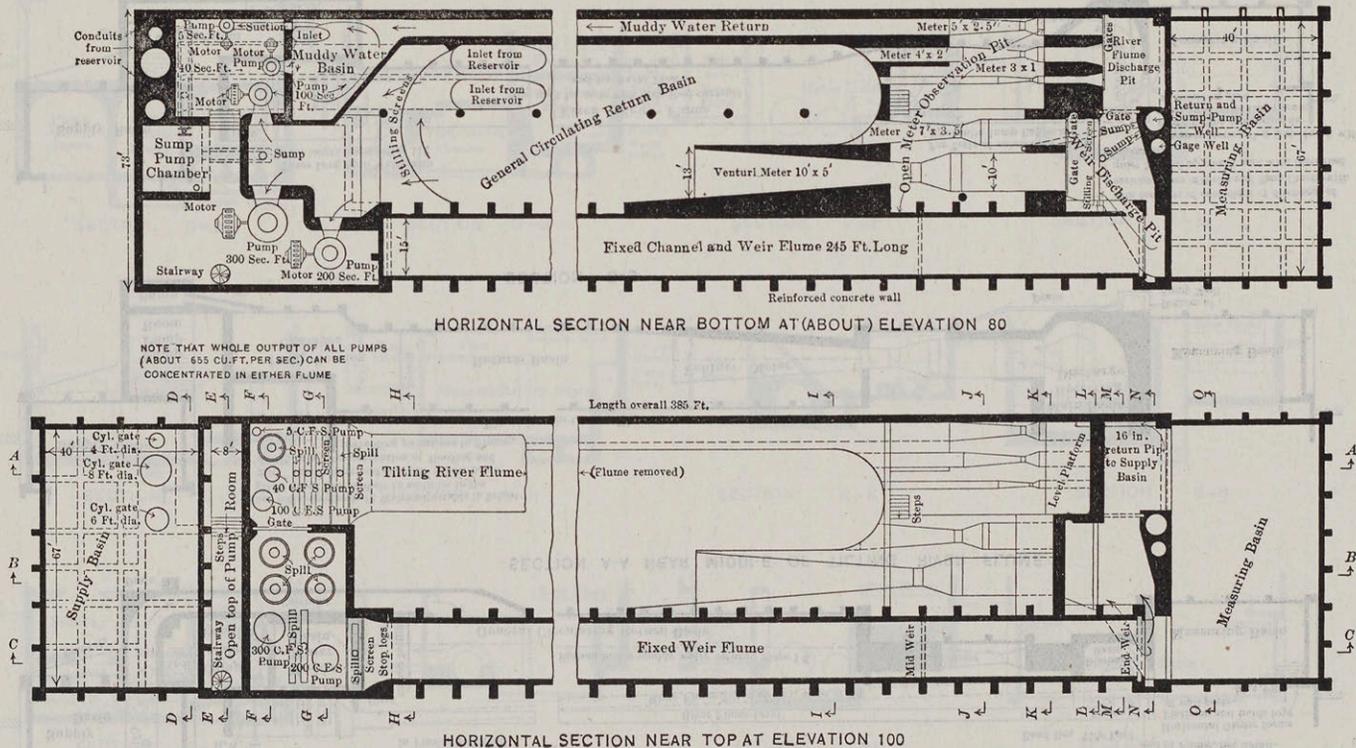
One of the main elements for producing this precise measurement in the basin is a swinging gate, with a sharp edge, and electrical contacts, by which the diversion into or out of the basin, can be effected and recorded with a precision of  $\frac{1}{50}$  sec. The details of this gate are not shown in the illustrations but their position is indicated in the lower right corner of Fig. 19.

Obviously, while large quantities, from 100 to 600 sec. ft. are being circulated, there must be a supply to compensate for the water diverted into the measuring basin. This is provided in the elevated supply basin, which has quick-working balanced cylinder gates interlocked electrically with the swinging gate at the measuring basin. Care has been taken to arrange the conduits leading from the supply basin into the general reservoir beneath the floor, the "General Circulating Return Basin" in Fig. 18, so as to minimize violent waves, and permit the energy to exhaust itself mainly in rotating the mass of water.

A matter which the speaker has found to give great difficulty in precise hydraulic experimentation is that of avoiding pulsations and securing almost absolute uniformity in the velocity of water in the experimental conduit. The best means found for securing this is by providing a slight surplus in the discharge of the circulating pumps and allowing this surplus to spill with a depth of hardly more than  $\frac{1}{8}$  or  $\frac{1}{4}$  in., over a widely extended weir crest. This is shown in outline in Fig. 18 and in the several sections on Figs. 19 and 20. This is also substantially the method used by Professor Engel. The total length of weir crest for this precise control is more than 400 ft.

The large centrifugal pumps for circulating the maximum quantities may be of a relatively cheap and simple type, in which high efficiency and extreme durability are sacrificed in favor of low first cost, because these larger pumps seldom will be used more than a few hours in the course of a year.

The discharge will rarely exceed 50 cu. ft. per sec., which is equivalent to a model river channel of 10 sq. ft. of cross-section and 5 ft. per sec. mean velocity. This, for 10-ft. lift, requires 57.6 theoretic h.p. and a motor of about 100 b. h. p., or 75 kw. For the brief series of experiments for deter-



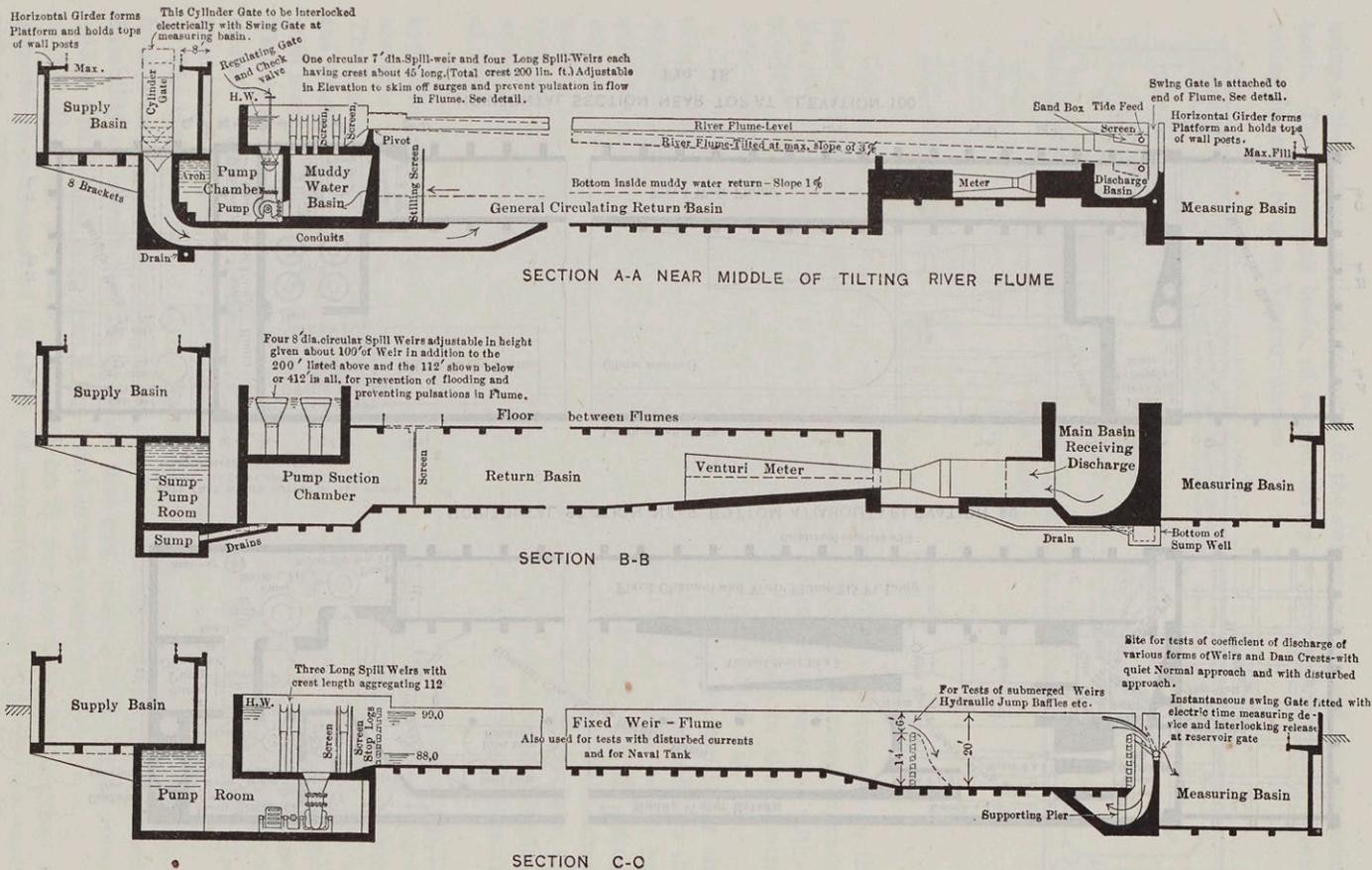


FIG. 19.

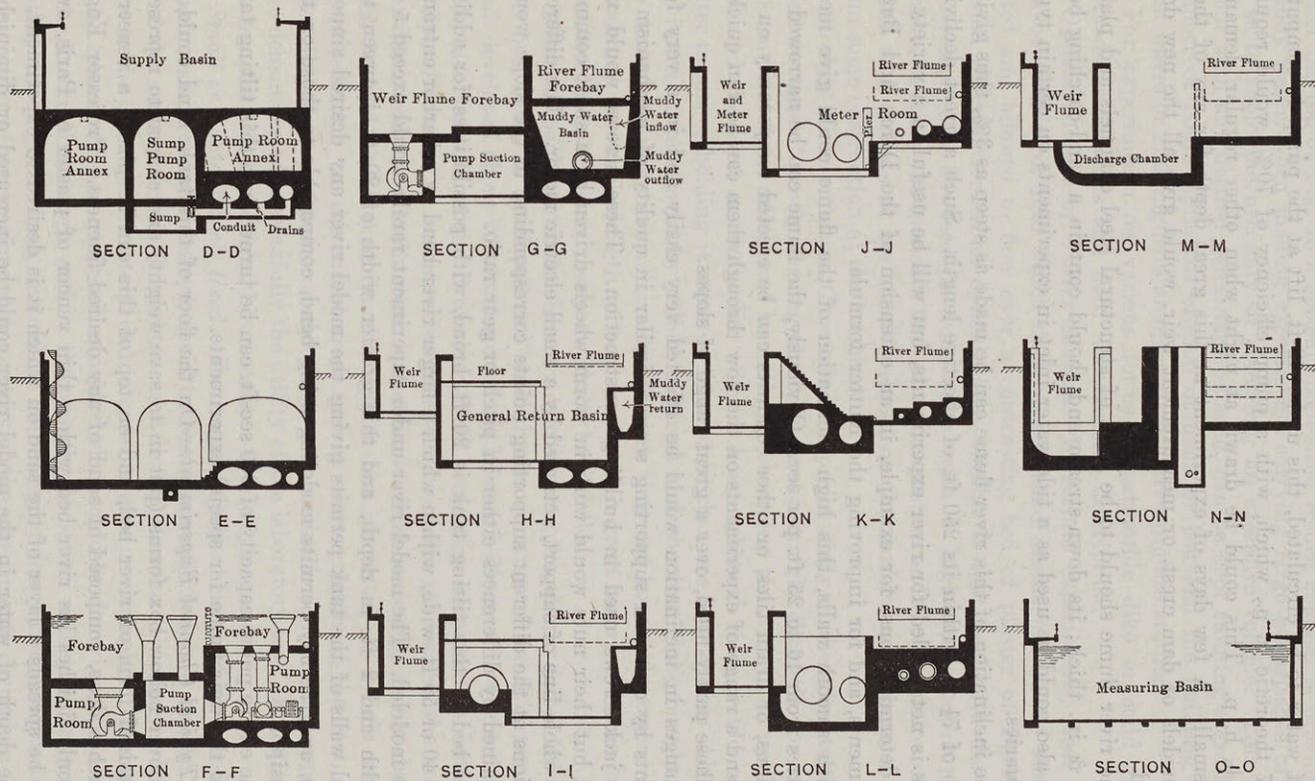


FIG. 20.

mining coefficients of discharge for new forms of dam crest or measurement weir, 15 ft. in length with  $5\frac{1}{2}$  ft. depth on the crest, or, say, 600 cu. ft. per sec. of water to be circulated, this under 12-ft. lift at the pump is computed at 817 theoretic h. p., which, with a pump efficiency of 70%, would require 1167 b. h. p. This could be drawn at night when other regular demands were small. A few days of experiment at this great depth for any of these new models of dam crest, or measurement weir, would give all the new data needed.

The river flume should to be built of structural steel channels and plates about  $\frac{1}{8}$  in. thick; its down-stream end should contain a sand-catching box, which also could be used as a tide-water inlet in experiments on certain types of estuaries.

The inclination of this river flume can be made as steep as 3%, thus giving a drop of  $7\frac{1}{2}$  ft. within its 250 ft. of effective length. Such a great declivity as this is not needed for river experiments, but will be useful in a variety of other determinations, for example, in an extension of the Darcy and Bazin experiments, and for improving the Kutter formula.

With smooth walls, this high inclination of the flume could give mean velocities from 16 to 25 ft. per sec. Obviously, the flume can be narrowed by partitions, or drain tiles, or other conduits can be erected temporarily on its floor, and a range of experiments on the flow through them can be run quickly with these partly filled, over a great range of slopes.

Changes in inclination would be effected very easily and in a very few moments by cast-iron supporting screws similar in quality of mechanism to cheap jack-screws used in building construction. These screws would not rotate, but their nuts would work in worm wheels driven by a shaft common to the whole line of support, actuated by a small electric motor. The different elevations at the different supporting points corresponding to the slope would be obtained by differences either in pitch or gear ratio.

The bed of this tilting tank is 20 ft. broad, with possibilities for adding a bay, 40 or 50 ft. wide, within which a larger river bend or a harbor entrance can be modeled. The model river under experiment rarely would exceed 5 ft. in width and 2 ft. in depth, and this greater width of 20 ft. between the normal walls of the tank permits giving the model river any desired sinuous course, and the bay permits modeling a big bend, comparable to those on the Mississippi.

The entire pump capacity of 600 sec.-ft. can be turned into this tilting tank or into the weir flume for special experiments.

*A Typical Channel Experiment.*—On the floor of this tank, sand could be placed over hollow box forms (put in to save weight) and shaped to represent any desired form of river bed, and on top of this can be placed a veneer a few inches deep, composed of sand of any desired fineness. Professor Engel commonly finishes his river bed with a thin veneer of plaster of Paris, over which he spreads a layer of the sand on which it is desired to experiment.

The depth of water in the model river could be increased or diminished quickly by the outlet gate on the pump. At the close of an experiment the

water can be drawn out quickly and photographic record made of the condition in which sand-bars and erosion have reformed the river bed.

At the top of Fig. 18 a special small-sized return channel is provided for muddy water, when making experiments carrying large percentages of sand, so as to avoid the necessity of providing an excessive volume. This water, laden with any desired percentage of sand, can be kept running steadily any number of hours while the erosion of bank or bed and the building up of sand waves or crossing-bars at reversals of curvature are studied.

For experiments on various forms of permeable dike or solid groyne, methods are obvious and need no extensive description.

*Optical Studies of Vortex Motion.*—In certain experiments, clear water can be circulated, into which dark-colored sand grains of various sizes are sifted and allowed to flow over a contrasting bed of plaster of Paris, and special illumination in an optical plane, similar to that used with the ultramicroscope can be used in connection with a high-speed motion-picture camera, to study the intricate laws of vortex motion and the formation of such swirls and vortices as are often observed on the surface and appear to come from some obstruction at the bottom.

*Straight Versus Curved Channels.*—A special study of the advantages and disadvantages of gently curving channels *versus* straight channels, for navigation and for flood relief, can be made by observing the bars built up in one case and the sand waves in the other. A straightened river would require better means of holding it securely in position than are now known. Although the forms of revetment by willow mattress and concrete block now built by the Army engineers are admirably efficient, they are hopelessly expensive for protecting the whole length of both banks of a great river, and this has led to numerous inventions, many of which have failed.

Means of bank protection by rows of concrete piles, deeply jettied below the river bed, could be developed and studied, also variants of the Stickney bank-head, developed about 20 years ago on the Missouri River, with various curvatures, also variants of the Brownlow Weed protection developed in India.

*Spur-Dikes.*—The comparative merits of various shapes for the ends of spur-dikes and their inclination to the bank could be tested, and perhaps as much learned about them in six days in the laboratory as by six months' experimentation on the actual river and at one-twentieth of the cost. Professor Engel's experiments on the shape and inclination of groynes appear to have demonstrated successfully the utility of the laboratory test. Fig. 21 shows few samples of his photographic records.

*Small or Large Models Used.*—For certain quick changes of river bed, etc., experiments, whenever desired, could be run in a model bed on a smaller scale, or of the same dimensions as those used in the German laboratory. In contrast to the German laboratory, and in order to give an example of the capacity of the laboratory now proposed, consider what could be done in it on a model of the Lower Mississippi, and let the experiment be run with quantities representing the highest flood, instead of representing low-water conditions and improvement of navigation, such as most of the experiments carried on in the German and other foreign laboratories.

*Small Scale Experiment.*—For an extreme example, let there be modeled in the river flume a winding stream with a soft sandy bed in form representing accurately to scale some part of the Lower Mississippi, with horizontal dimension, all in the proportion of 1 ft. in the model to 1 000 ft. in the river. The vertical scale can either be the same or can be increased and made in the proportion of 1 ft. depth in the model to 100 ft. in the river. Probably this distortion would not disturb seriously the results in certain experiments. It would be analogous to experimenting on the discharge over a section of dam crest only 3 ft. long where the entire structure had a crest 30 ft. long. A check test could be run subsequently on natural scale.

The 250-ft. length of experimental tank would then represent 250 000 ft., or nearly 50 miles along the valley in a straight line, and 20 ft. of width would accommodate a river bend with an ordinate of nearly 4 miles, and the broad tank could take in a bend of nearly 10 miles ordinate.

Corresponding to a 100-ft. flood depth in the Mississippi there would be a 1-ft. depth flowing in the tank, and instead of a main river channel 3 000 ft. or 4 000 ft. wide the model channel would be 3 or 4 ft. wide. Seldom would the difference in size between the original and the model be so great; the largest scale practicable should be used. In many problems, a scale of 1 to 20 would be best.

The wide range of dimensions over which many hydraulic formulas apply is truly remarkable, if only one starts above the range where the molecular forces of surface tension, capillarity, and viscosity play important parts. The same law controls discharge of orifice or Venturi meter of 0.1 in. and 100 in. in diameter.

*Studies in Which the Proposed Laboratory Could Be Used.*—Forty studies are suggested for which the river flume would be useful, following which are listed some for which the weir flume could be used.

- 1.—A further investigation of Thompson's theory of scour at river bends due to spiral flow.
- 2.—An investigation of the path of material scoured out from the concave shore at a bend, whether moved across the river, or to a down-stream sand-bar.
- 3.—Best inclination of the banks and the best shape for the ends of spur-dikes in a straight river channel for producing minimum scour at the end of the spur and the best shape for preventing undermining a submerged spur by scour.
- 4.—Relative merits of permeable and impermeable spur-dikes of various forms.
- 5.—Best form for a sub-surface dike reaching from the bed to slightly above low-water but submerged at high water, and thence extended up the bank by a thicket of willows or other trees.
- 6.—Development of shape and construction of cross-section of spur-dikes faced with rip-rap for minimum cost.
- 7.—Necessary distance between spur-dikes in relation to width of river for maintaining straight alignment and protecting the shore between spurs.

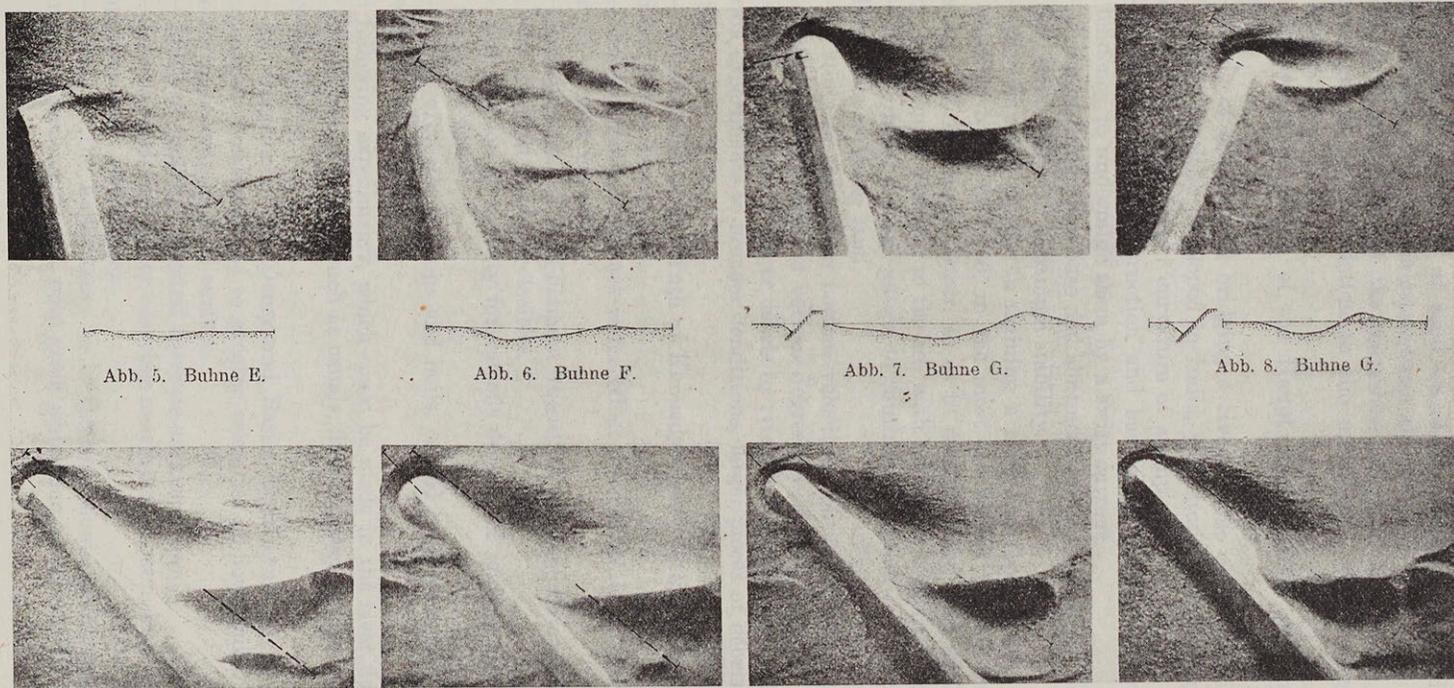


FIG. 21.—A FEW EXAMPLES FROM PROFESSOR ENGEL'S LABORATORY TESTS OF FORMS OF GROUYNE AND THEIR EFFECTS ON SAND DRIFTS.

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Fig. 1



Fig. 2



Fig. 3



Fig. 4



8.—Formation and travel of sand waves in straight and curving rivers, and their relation to a navigable low-water channel.

9.—Study of the effect of the coarseness of grain, as between fine sand and coarse gravel, in its relation to the upbuilding of cross-over bars on curved rivers.

10.—Study of the action of the Haupt reaction jetty and its limiting curvature.

11.—Study of economy in bridging a river by the construction of "Bell-Bunds" similar to those developed in India, with study of minimum distance between abutments and proper curvature of alignment.

12.—Investigation of obstruction and back-water caused by bridge piers and of tendency to undermine them by a swift current.

13.—Form of bridge pier base and abutment for producing minimum scour on the bed, combined with maximum stability.

14.—Miscellaneous studies in training a river like the Missouri or Platte, within erodible banks and bed, in the most economical way for flood relief, by causing it to dig itself deeper, so as to minimize the need of levees, and to carry its sediment forward to the sea with minimum deposition *en route*.

15.—Best form of harbor jetties to minimize obstruction of entrance by littoral currents carrying sand.

16.—A study of maximum bottom velocities consistent with stability for various sizes of sand grain and various degrees of adhesion.

17.—Transportation of larger débris by rivers, and extensions of the Gilbert California experiments to broader conditions, larger pieces of débris, and high velocities.

18.—Investigation of the truth of Kennedy's law relating to the movement of sand and silt in suspension.

19.—Develop the law of back-water effect from dams and obstructions in straight or curving channels.

20.—Investigation of fluid-filament theory of parallel flow, *versus* vortex motion near sides, at various velocities.

21.—Distribution of velocity for various degrees of roughness of sides and bed of stream or flume.

22.—Study of vortex motions and boils, caused by obstructions at bottom or by collision of currents.

The following experiments, which could be made in the river flume, relate to flow in artificial channels, such as canals, flumes, sewers, culverts, and large pipes partly filled:

23.—An extension of the Darcy and Bazin experiments, of 60 years ago, to other shapes of channel and to greater velocities of flow, and with various definite forms of roughness of surface.

24.—Effect of twisting or spiral currents on loss of head.

25.—Loss of head with water carrying nearly a maximum load of sediment, in comparison with clear water.

26.—A test of the Eads theory as to the maximum percentage by weight of sediment of various sizes of sand grain which can be transported at a given

velocity. (The probabilities are that nowhere on the Mississippi or even on the Missouri is the water saturated with sediment, and that much higher percentages of sediment could be carried in a regular channel, if it could be dug up from the bottom by the velocity and kept moving in a straightened river.)

27.—Determine the relative proportions of sediment that can be carried in suspension at various high velocities, when walls of conduit are relatively smooth and when roughened, or when the water is thrown into eddies by spur-dikes.

28.—Determine more precisely the relations of roughness to laws of flow. (This can be done readily with the tilting trough, for a wide range of velocities, by changing the depth, or the speed of the pump, or by control of its discharge valve.)

29.—Develop formulas of discharge for sewers or conduits filled to various depths.

30.—Effect on velocity or loss of head caused by a roughening of various proportions of the wetted perimeter.

31.—Laws of loss at sudden enlargements.

32.—A study of tidal rivers in which the action of the rising tide on the river flow is simulated by water introduced at down-stream end of flume.

33.—Test the effect of wave transmission for various depths and forms of channel, and effect of pulsations of flow on sand waves and sand-bar formation.

34.—Determine the law of flow for the "bore," or "cloud-burst" type of flood wave, at various inclinations of bed.

35.—Repeat the Francis "white-wash experiment," under various conditions, for determining course of threads of current.

36.—Study of straight *versus* curved river channel for Missouri River conditions.

37.—Study of curved *versus* straight channel for a deeper river, as for certain bends on the Lower Mississippi.

38.—A model of the mouth of the Mississippi on a horizontal scale of about 1 to 100 might prove very instructive in finding the most efficient means of making the South Pass available for deep-draft steamers with a minimum of dredging.

39.—Possibly also some extremely useful information could be had by experiments on the model of the proposed spillway from the Mississippi to Lake Borgne, as to the results that would be achieved in flood relief and subsequent silting or absence of silt in the river mouth.

The City Engineer of New Orleans has presented a tentative design for an extremely broad spillway.\* The speaker is inclined to believe that an extremely narrow but deep spillway, only one-fifth of the width of the other design, would cost less and give better service. Models could serve to point the way to the best possible design before spending the suggested \$4 000 000 or \$5 000 000.

\* See Fig. 9, p. 1165.

40.—Along the Colorado River below Yuma, Ariz., in view of the present and potential values at risk in the Imperial Valley of California, some new form of groyne, and proper spacing for it with willow plantings between the groynes, could be worked out advantageously by experiment in the proposed laboratory, combined with experiments on the river.

For the weir flume, the following studies are suggested:

41.—Extend the Francis weir formula by new experiments to greater depths up to  $5\frac{1}{2}$  ft. with crest 15 ft. long, or to greater depths with shortened crest.

42.—Test in great variety the effect of swirls and irregularities of flow in the current approaching a standard weir, on accuracy of measurement.

43.—Determine the coefficient of discharge for various forms of round-crest weir and, incidentally, experiment to develop a new standard form of weir less subject to error from disturbance by approaching currents and contraction, than is the present standard sharp-crest weir.

44.—Determine form of crest for maximum discharge over a dam.

45.—Test effect of submergence and back-water on weirs at various depths and proportions of back-water, to a depth of 5 ft. below the crest. More extended experiments on this are greatly needed.

46.—Test thoroughly the new Herschel type of weir and its scheme of depth measurement.

47.—Determine the coefficients for discharge over models of many dam crests actually in use and now utilized in America for metering the flow of rivers.

48.—Check and extend the deep-waterway dam-crest experiments made some years ago at Cornell University.

49.—Determine coefficients for various types of sluiceway, some of which are utilized in gauging the discharge by the Hydrographic Department of the U. S. Geological Survey.

50.—Experiment on ordinary canal head-gate sluices of different forms, for determining the coefficient of discharge for various heights.

51.—Test the effect of twisting and disturbed flow in channels on the accuracy of measurement by current meters of various types. There is great need of additional data on this. Some types of current meter are much more accurate than others in disturbed currents.

52.—Develop most accurate type of current meter for the disturbed currents found over a cobblestone bed, or other rough bottom.

53.—Develop and test portable Pitot tube velocity meter and study the errors that may be caused by waves and twists of current.

54.—A study of the hydraulic jump, or standing-wave, phenomena.

55.—A study of "fall increaser," for use in economizing water power on rivers subject to high back-water.

56.—Study of various types of energy absorber for the foot of overfall dams, to lessen danger of scour on soft river beds.

57.—Develop best type of baffle-piers, for foot of an ogee overfall.

58.—Develop an open top Venturi type of sluice-gate for the head-gates of irrigation canals and other waterways.

59.—Develop the best form of bellmouth for tunnels to be used as the bypass of the dams under construction.

60.—Determine the most efficient angle of divergence for a Venturi tube, with smooth current of approach, and with disturbed and twisting currents of approach, as in the draft-tube of a water-wheel. It is possible that these studies would aid in the economics of power development.

61.—Study the limiting conditions for precision of measurement with Venturi meters of various types, with disturbed approach currents.

62.—Experiment on centrifugal pump discharge for a wide range of velocities and with throttled inlet or outlet.

63.—Determine the overturning effect of currents at various high velocities on bridge piers and similar structures of various shapes.

64.—Test the limitations of the siphon spillway with greater depth of throat, up to 10 ft. in height; try to get nearer to 100% efficiency of discharge; develop better forms for quick exhaust of air; and generally improve and standardize the design.

65.—The weir flume would be useful as a naval test tank, for certain conditions of currents, by holding the model still while the current flows swiftly past. It would be particularly instructive, for cases in which high velocity runs in the ordinary naval tank would be too brief.

*Scanty Literature.*—It is difficult to explain why the United States, with all its progress in experimental engineering and its widespread application of laboratory methods, has lagged behind European practice in the use of the laboratory as an adjunct to river training, except by the fact that in the United States nearly all the river training and harbor improvement work has been in the hands of the U. S. Army Engineers; and it seems to have been traditional in that Corps to experiment on the full-sized specimen in the field, which is a good way if it is not too expensive.

In an address on Army Engineers and River Improvement\* the Secretary of War (the Hon. J. M. Dickinson) said: "Their powers and duties are fixed by Congress. They are prohibited by Congress from making original investigations or recommending projects." This sounds broader than the fact, and it is thought that the Secretary did not mean to say that original physical and hydraulic investigations are forbidden. Still, one gets an impression that the Corps has contributed fewer papers on river science to the *Transactions* of this Society, and has published fewer scientific memoirs on river and harbor science in the past 40 years than were published by the members of corresponding Corps abroad. No one familiar with the personnel of this famous Corps doubts that the ability is there. The Humphreys and Abbot report on the physics and hydraulics of the Mississippi was a far better work than any of its kind ever published previously anywhere in the world, and some examples of what they can give to the Profession are found in the many admirable *Professional Memoirs* and *Occasional Papers* published mainly for the information of members of the Corps, and thus circulated less widely than their merit deserves. There must be some obstacle in the system under which

\* *Professional Memoirs*, 1910, p. 75.

they are constrained to work, some lack of encouragement to individual initiative for scientific research or to publication, by the young officer, and an overloading of the older ones with the routines of disbursements, auditing, and the difficulties involved in frequent change of station.

All engineers wish that some of the younger officers might be directed to prepare a new book on the physics, hydraulics, and structures of the Mississippi and Missouri, and have it finished in 1925.

Many business men in the Valley and many engineers outside the Corps of Engineers are deeply interested in these great problems, the solving of which means so much to general prosperity, and all would like to see the Army Engineers address a wider audience.

#### FOREIGN RIVER-TRAINING LABORATORIES

It is of interest to examine the work of European laboratories in which important contributions to the improvement of harbors and estuaries in England and France were made many years ago by such famous engineers as Osborne Reynolds, Vernon-Harcourt, Fargue, and others.

It was by a laboratory experiment, forty-five years ago, that Professor Thompson, of Glasgow, discovered certain of the most important facts as to the progress of bank erosion by the action of spiral currents.\* In matters of this kind, because of the depth of swirling turbid water in the river flood, it is almost impossible to find a clue, except under the controlled conditions and smaller volume of the laboratory; but the clue, once gained, can be proved in the field. This important principle of spiral currents at river bends is dealt with only lightly in American textbooks, and most of them do not mention it.

Many years ago the English engineer, Hearson, noting the remarkable developments from Froude's experiments on the resistance to the propulsion of ships by laboratory models, was one of the first to propose laboratory models for studies of control of river and harbor currents, and he deduced mathematical laws for the proper relation of dimensions and forces.

Professor Osborne Reynolds, of Manchester, England, one of the most distinguished of English scientists, proposed the use of models,† for studying the movement, depths, and regulation of currents in tidal basins, and discussed the mathematical relations of the small-scale model to the larger problem. Vernon-Harcourt, many years ago, used a model in his study of the estuary of the Seine, and Eger, Dix, and Seyfert reported their experiments at Berlin on a model of the River Weser.‡

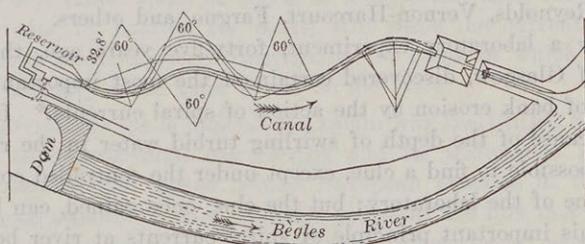
In Germany, for many years, three river-training laboratories have been maintained in connection with engineering schools and for the use of the Government engineers. The most noteworthy is at Dresden, presided over by Professor Hubert Engels, from which many important practical studies have been reported, and the benefits of which to hydraulic science and art shown in Professor Engel's book, entitled, "Wasserbau."

\* *Proceedings*, Royal Soc. (London), 1876, p. 356.

† *Proceedings*, British Assoc. for the Advancement of Science, 1887, p. 555.

‡ *Zeitschrift für Bauwesen*, Vol. 56 (1906), p. 232.

Italy, where the art and the science of river control had their birth, and where many serious problems are caused by torrents and by rivers flowing through delta plains, bearing large quantities of sediment, was considering two hydraulic laboratories prior to the World War, and very recently has resumed the movement for their establishment. An experienced engineer, Sig. Ettore Scimemi was sent on a tour of inspection and research to sundry hydraulic laboratories in foreign countries, and the results of his investigations were published in 1922 by the Royal Hydrographic Office.\* This volume contains outline drawings of the research laboratories at Dresden, Berlin, Karlsruhe (see Fig. 26), and Vienna, and of the smaller laboratories maintained in connection with the technical schools of Grenoble, Toulouse, and Monaco. It also illustrates the laboratory alongside the canal of Bourgogne, made famous by the experiments of Darcy, and the experimental canal of Fargue, Fig. 22, at which, in connection with observations on the river, he devised his rules for regulation of river courses on curves, many years ago, before the conveniences of the modern river-training laboratory had been developed.



GENERAL PLAN

FIG. 22.

Among valuable features of Sig. Scimemi's report are two admirable bibliographies, one containing 42 titles on hydraulic laboratories, and the other, 60 titles on the use of models in hydraulic research. That on models begins with a reference to the *Proceedings* of the Italian Scientific Society at Modena, telling how Bonati in 1804 in a small wooden flume reproduced phenomena observed in the Canal Bianco during the flood of 1767, and thereby obtained data on the formation of eddies in rivers with a shifting bed. Evidence of the thoroughness with which Sig. Scimemi made up his list is found in the fact that it concludes with a reference to the experiments on models of the Gilboa Dam.†

It is now proposed to consolidate at once the activities of two important Italian institutions devoted to hydraulic experiment, those at Stra and at Santhia, in a single new hydro-technical institute which is to contain the new Italian National Hydraulic Laboratory.

While urging the construction of this laboratory for the information of Italian engineers, Sig. Scimemi notes that Professor Myere-Peter, of Zurich, has recently been urging on the Swiss Government the need of that country

\* "Gli Istituti Sperimentali di Idraulica all' Estero."

† *Proceedings*, Am. Soc. C. E., September, 1922, p. 1503.

for a similar laboratory, and a recent Dutch engineering journal quotes at length the results from Professor Engel's laboratory, at Dresden, giving photographic views, and urging a National Hydraulic Laboratory for Holland.

*Vienna Hydraulic Laboratory.*—The hydrographic service begun in Austria in 1894 gave a strong impulse to hydraulic investigation, and the Government's central hydrographic office, concluding that it was necessary to study the motion of water in rivers by using models, worked out a project for this in 1903.

Among the interesting special apparatus in this laboratory is one for photographic record of the crossing profiles and for measurement of the water levels. This consists in brief of a special projection lantern traveling on a light railway over the flume, by which a strong thin sheet of light is projected in a vertical plane which intersects the model channel and develops a strong, thin, luminous line on the bed, defining the section. In front of this optical section a camera is arranged with line of vision at right angles to the luminous plane in such a way that the profile of the fluvial section is presented on the sensitive plate with dimensions strictly proportional to the section of the model.

The general outline is shown in Fig. 23.

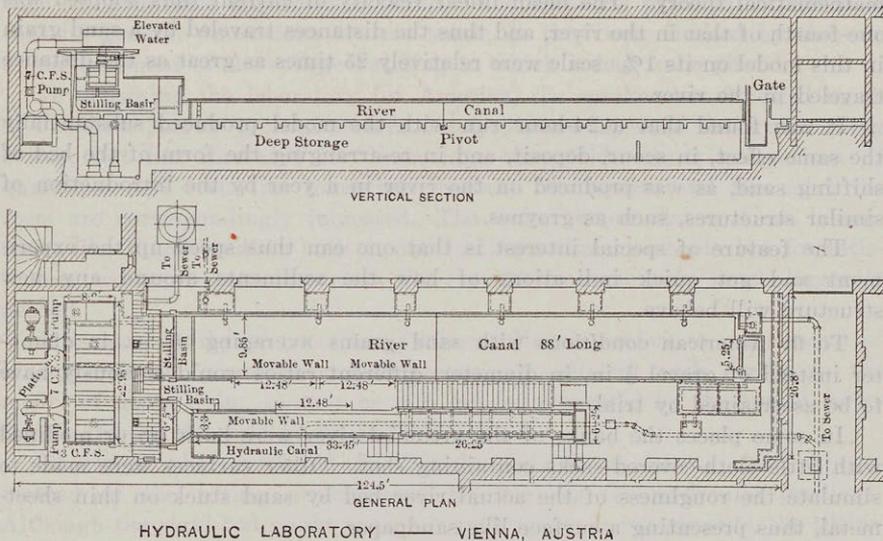


Fig. 23.

*Berlin Hydraulic Laboratory.*—The laboratory of the Experimental Institute of Hydraulic and Naval Construction of Berlin dates back to 1906, but in recent years has been devoted solely to studies of the motion and resistance of ships and experiments on screw propulsion, and thus in a way its work has become overshadowed by that in the river-training laboratories of Dresden and Karlsruhe.

J. L. Van Ornum, M. Am. Soc. C. E., of Washington University, who gained much of his early engineering experience as a U. S. Assistant Engineer on Mississippi improvements, quotes extensively\* from the experiments on models at Berlin.† These experiments on models were for guiding improvements on the Rivers Weser, Vistula, etc. Professor Van Ornum quotes particularly from those on the Weser, and the preliminary investigation as to whether or not the model would represent truly the conditions in the river.

After some preliminary experimenting, with the model on a scale of 1 to 100, it was found best to use in the model a sand grain about one-eighth the average diameter of the gravel in the river, instead of the ratio (1 to 4.6) which would give precisely 1% of the cubical content of that in the river.

There was recourse to both theory and trial in finding the proper relations of discharge and surface slope in the model to those of the Weser, which varies greatly in depth from low water to high. Finally, a relative discharge of 1 to 40 000 was selected, whereas the area ratio is obviously 1 to 10 000, and the slope finally adopted was 0.021 where that in the river was 0.00014, or 15 times as great, although, at first, theory required much more.

The criterion was to adopt such slope, discharge, and sand grain ratios as were found to reproduce or parallel best the actual work performed by structures in the river, rather than a set of ratios derived from imperfect mathematical theory. The mean linear velocity of current thus adopted was one-fourth of that in the river, and thus the distances traveled by a sand grain in this model on its 1% scale were relatively 25 times as great as the distance traveled in the river.

It was found that a 24-hour run with the model produced substantially the same effect, in scour, deposit, and in re-arranging the form of the bed of shifting sand, as was produced on the river in a year by the introduction of similar structures, such as groynes.

The feature of special interest is that one can thus speed up the experiment and get quick indications of how the sediments around any new structure will behave.

To fit American conditions with sand grains averaging  $\frac{1}{20}$  in. in diameter instead of gravel  $\frac{1}{8}$  in. in diameter, different ratios would obviously have to be ascertained by trial.

In some places the banks of the artificial river were built up or modified with little cloth-covered sacks containing shot. Other surfaces were made to simulate the roughness of the actual river bed by sand stuck on thin sheet-metal, thus presenting a surface like sandpaper.

It is noted that this work at Berlin was begun only about 16 years ago, and was soon interrupted by the use of the laboratory as a naval tank.

Professor Van Ornum's review shows that although all the details of proper ratios of velocity, size of grain, and slope had not yet been fully determined, it was demonstrated that experiments with models of groynes in the laboratory foreshadowed in a general way what happened in the bed of the river.

\* "The Regulation of Rivers", pp. 163-172.

† Described originally in *Zeitschrift für Bauwesen*, 1906, pp. 232-244; and 1907, pp. 67-78.

There seems to be no doubt that the process can be developed to foreshadow results with admirable precision and great economy.

*Dresden Hydraulic Laboratory.*—The present laboratory, built in connection with the new technical school at Dresden, Germany, in 1913, is substantially a large and improved copy of the laboratory built ten years earlier in one of the buildings of the old technical school. In this laboratory, experiments helping to solve some of the practical problems of the principal rivers of Germany had been made, also studies for lessening silt obstructions at the entrance to the harbors of Ymuiden, in Holland, and various river harbors in Germany. Certain problems of the Danube have also been worked out in this laboratory, and a great variety of fundamental work has been done on the formation and erosion of sand-bars and the proper shape for spur-dikes, groynes, harbor entrances, the form of sea-walls, etc. The general arrangement of the laboratory is shown in Figs. 24 and 25.

The speaker visited this laboratory about 10 years ago, after he had inspected its smaller predecessor, and was greatly impressed with its possibilities of usefulness. From time to time its Director, Professor Hubert Engels has favored the speaker with publications about its work, and doubtless much of the excellence of his treatise on river hydraulics presented as part of his monumental book\* on water structures is a result of his having such an admirable apparatus at hand. The speaker's principal criticism is that its general dimensions are too small, as they were limited by the size of the basement of the college building in which it had to be placed.

In designing the laboratory for America, the speaker has followed much of Professor Engels' general design, simply because he could think of nothing better; but has increased its dimensions three-fold. As a comparison of quantities and costs lies somewhere between the square and the cube, the costs are correspondingly increased. The writer hopes that a dozen laboratories like Engels' will be built at our leading technical schools, but for satisfactory work on great American river problems something much larger is needed.

It is here worthy of note that Professor Engels prefers to make many of his experiments on scour and deposition of sediment with depths in the model of about 8 in., so that he will not be prevented by the turbid water from watching the sand grains in their course.

The latest photographs of the Engels' river flume show a rigid support instead of the tilting arrangement for varying the hydraulic gradient. Although the rigid bed might serve for ordinary river experiments, the tilting bed serves so much better for a great variety of other experiments, such as flow in partly filled conduits on various gradients, and in a line of experiments covering a wide range for deriving a formula much better than that of Kutter, that the tilting form should be adopted for the proposed laboratory.

At the University of Stockholm, Sweden, there appears to be an excellent hydraulic laboratory adapted for river training problems and many others, according to three pamphlets in the Swedish language recently received by

\* "Handbuch des Wasserbaues", Leipzig, 1921.

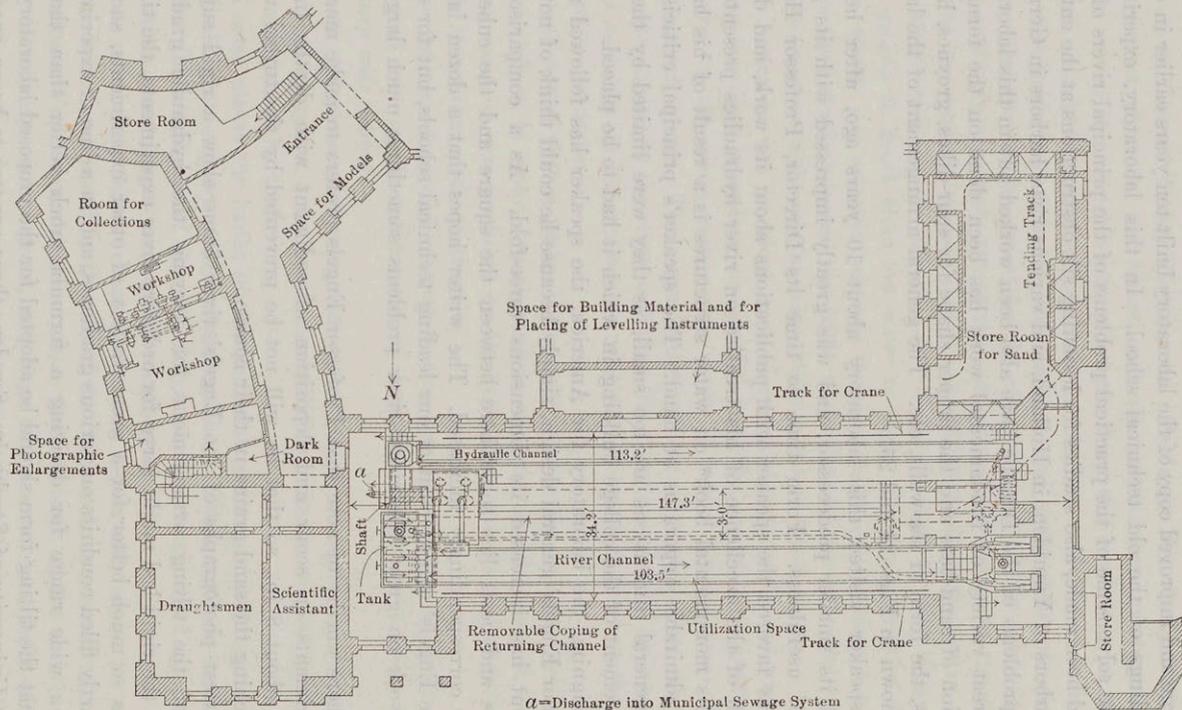


FIG. 24.

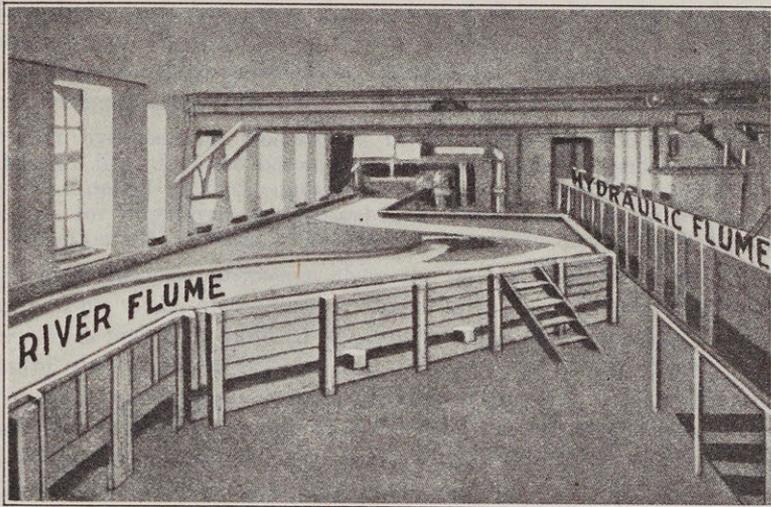


FIG. 25.—VIEW OF HYDRAULIC LABORATORY, DRESDEN, GERMANY.

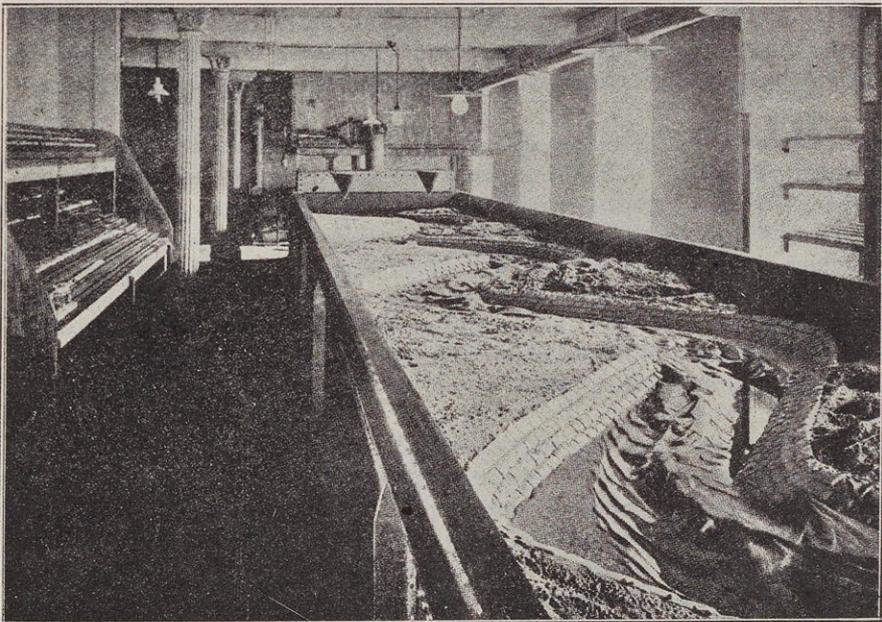


FIG. 26.—AN EXPERIMENT IN PROGRESS AT THE KARLSRUHE LABORATORY.

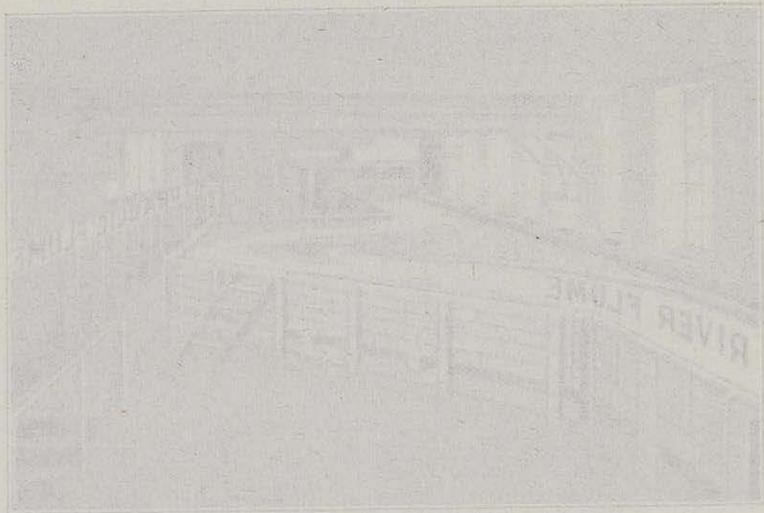


FIG. 1.—View of Hybridization Laboratory, Berkeley, California.



FIG. 2.—An experiment in progress at the National Laboratory.

the speaker from Professor W. Fellenuis. Some excellent researches appear to have been made here upon the erosion of shores by waves and protective works.

*Laboratories Recommended by Navigation Congress.*—At the International Navigation Congress of 1912, among other things, it was recommended:

“That hydrotechnic laboratories intended for the study, on small scale models, of life of rivers become of more and more extended use, and that they be supplied with the means necessary to experiment with the various processes for improving the navigability of rivers and, in so far as possible, in connection with the studies and works carried out on the rivers themselves.”

At first, one feels misgivings about the small dimensions used by Professor Engels in his model of the flowing stream giving correct relations for the real river, which may be a hundred or perhaps a thousand times the linear dimensions of the model. Still, ordinary formulas for canals, pipes, weirs, and orifices, are substantially correct through a similarly wide range, and Professor Engels and many others state that the correspondence of behavior between model and original has been proved satisfactorily in many cases.

By testing a few samples of groynes, training walls, eddying rivers, eroding banks, and sedimentation bays, in both model and original, one could soon establish correction coefficients for the formulas of relation, even for such wide disparity as that presented by the Missouri and Mississippi and the model channel in the proposed laboratory.

#### PROPOSITION FOR A U. S. HYDRAULIC LABORATORY

In order to show that the present proposal for an American National Hydraulic Laboratory is no sudden fancy, but a long matured plan, it may be useful to trace its development. Perhaps it may be worth while also to state that the speaker's special interest in this matter is purely for the public good.

In his Presidential address\* the speaker sketched the development of hydraulic science and ended with statements to the effect that, as distinguished from the art, it appeared to have been mostly asleep during the past 50 years; and that engineers had neglected the study of means by which sediment-bearing rivers flowing through broad and deep alluvial deposits might be trained to dig for themselves deeper channels, in which, between permanent banks, they could carry their floods and their load of sediment peacefully to the sea. The speaker concluded by urging the construction of a National Hydraulic Laboratory, and told a little about the useful practical information that might be gained thereby.

On that occasion, the speaker had scant time and space for details, and in the present paper he will go somewhat farther in showing the practical application of such a laboratory to present problems, repeating only enough of what was presented previously to make the story readily understood.

The speaker's work in a hydraulic laboratory began alongside the Merri-mac River, more than 50 years ago, in experiments on the flow of water in pipes and over weirs and with instruments for measuring the velocity of

\* *Transactions, Am. Soc. C. E.*, Vol. LXXXV (1922), p. 1601.

flowing water; and his interest in such matters during the years between has had various periods of wakefulness and slumber. About four years ago, in China, during studies on the Yellow River, the speaker became deeply interested in the way that this river, perhaps the muddiest great river in the world, digs its bed deeper\* during a flood, and refills this deepened channel gradually as the flood subsides, and he was greatly impressed by the possibility of making use of these forces of scour and deposition in training a river to flow along a prescribed narrow course, dig its bed deeply, and carry its burden of silt in suspension. It occurred to him that by learning to control these great forces of Nature we could greatly lower the cost of flood relief for the oft-devasted Valley of Huai. He even ventured to mark out a new flood relief channel on a straight line course, and to suggest that perhaps Nature could be coaxed to do a large part of the digging.\*

From time to time as the speaker's work has brought him in contact with river problems in various parts of the United States, Canada, and Mexico, he has regretted profoundly that there was not one laboratory on the American continent, comparable to those abroad, for studying some of these intensely practical matters which cannot be investigated properly in the field alone.

About three years ago, at a little gathering of engineers in San Francisco, Calif., soon after the late Professor Gilbert had published his researches on the transportation of river débris, the speaker urged on the attention of those present, the good that could come out of a larger hydraulic laboratory at their university in helping to solve some of their pressing local problems, such, for example, as flood relief along the Sacramento and its tributaries, and the regulation of the torrents that from time to time tear down along some of their delta cones, as at the San Gabriel Wash, near Los Angeles.

Some months later, in China, in a public address before sundry Government officials interested in conservation, the speaker stated that if, in connection with solving some of their great flood problems, they could build a suitable hydraulic laboratory, its wise administration might pay dividends on its cost at the rate of 1 000% per year.

A year ago, while addressing the Washington Society of Engineers on the flood problems of China and the Yellow River, the speaker pleaded the cause of a National Hydraulic Laboratory so earnestly as to impress Secretary Wallace, of the Federation, with the value of the idea, which he promptly transmitted to Senator Ransdell of Louisiana, who thereupon introduced into Congress a Joint Resolution to Establish a National Hydraulic Laboratory,† and to appropriate \$200 000 for that purpose. It was proposed to establish it in the District of Columbia, in connection with such Bureau as the President of the United States might designate for the conduct of research, experiment, and scientific studies in connection with the problems of river hydraulics and flood control.

At a public hearing in Washington on September 8, 1922, before a Subcommittee of the U. S. Senate Committee on Commerce, the speaker pre-

\* See "Flood Problems in China", *Transactions, Am. Soc. C. E.*, Vol. LXXXV (1922), p. 1405.

† S. J. Res. 2-9, 67th Congress, 2d Session

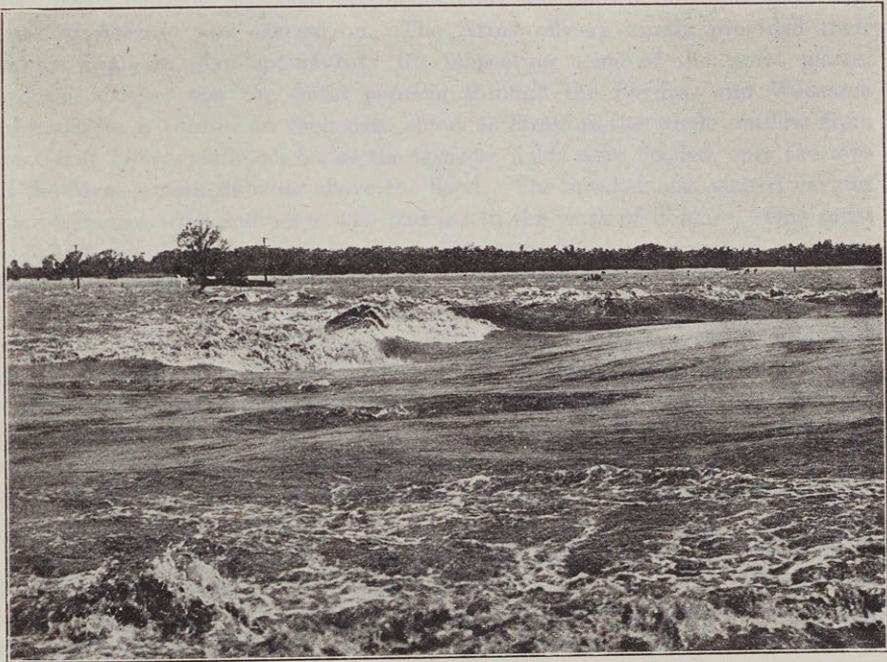


FIG. 27.—THE POYDRAS CREVASSE.

The following table shows the results of the observations made at the various stations during the period from 1880 to 1885. The observations were made at the following stations: ...



The following table shows the results of the observations made at the various stations during the period from 1880 to 1885. The observations were made at the following stations: ...

sented, by request, his reasons for believing that such a laboratory would lead to great economies and other important benefits in matters of flood relief, reclamation, and navigation, and submitted a series of drawings to illustrate his conception of the scale on which such a laboratory should be built.

*Observations of a Great Flood.*—In April, 1922, the speaker was in the office of the Assistant Chief of U. S. Engineers when reports were coming in of the highest flood ever known along the Lower Mississippi, and this prompted him to make a tour along the river, stopping for observation and inquiry at and near Memphis, Scotts Landing, Greenville, Vicksburg, Natchez, Baton Rouge, and New Orleans, reaching the lower points while the flood was still within about a foot of its maximum height. The speaker was treated with great courtesy by local engineers, and was shown how the marvelous work of defense was carried on. The Army officers kindly provided their service boats to give opportunity for inspecting some of the worst places, and the speaker saw the water pouring through the Poydras and Weecama crevasses in a volume in each case about as large as the whole outflow from the Great Lakes, while, as far as the horizon, fields were flooded, only the tops of the farm houses showing above the flood. The speaker also visited various near-crevasses with engineers who had led in the work of defense. One must have a personal view of this kind in order to realize the terrors of a mighty Mississippi flood.

All that the speaker saw and heard made a profound impression, that here was one of the greatest engineering problems in the world, and that greater advance than the record shows should have been made in 40 or 70 years of construction and study, with the expenditure of nearly \$200 000 000. It appeared plain that there was still quite as much need of a few thousands of dollars for scientific study, as for the \$40 000 000 asked for levees, and for the \$200 000 000 or \$300 000 000 desired for mattress revetments in order to protect the levees.

Early in November, 1922, when the Mississippi was near its lowest stage for the year, the speaker revisited the sites of the crevasses at Poydras (see Fig. 27) and Weecama, inspected river channel conditions near New Orleans, Natchez, and Memphis, and examined the sediments along the bank, which, within short space, varied from layers of clear, dry, firmly-packed, water-sorted sand grains to soft clay-like mud, that did not easily give up its water, and was almost devoid of frictional resistance.

This difference was plainly due to the vagaries of the eddying current and is well worthy of study by the physicist. The size of grain of Mississippi and Missouri sediments differs greatly from the coarser gravels and sands of certain European rivers from which many of the textbook data have been derived.

From the curious freaks of erosion witnessed, it seemed to be beyond all doubt that some of these great fundamental questions should be studied anew, and that the proposed laboratory would be extremely helpful.

*Inspection of Wood Brothers' Retards.*—At the Dayton Meeting of the Society, in April, 1922, in course of a two-day session devoted almost wholly

to problems of flood relief, Roy N. Towl, M. Am. Soc. C. E., showed a remarkable series of moving pictures of caving banks on the Missouri River near Omaha, Nebr., and also methods of protection known as the "Woods Brothers' System of Retards" (Figs. 28 and 29), which had been put in, by the advice of the engineers of the Chicago, Burlington and Quincy Railroad, for the protection of bridge abutments, with great success. He told of other examples of these "retards", which are a form of short permeable spur-dike, anchored securely by wire cables to concrete piles sunk far below limits of scour by the water-jet method. These retards have been subsequently introduced at other places for preventing the erosion of farm lands, with remarkable success. Their ordinary arrangement is shown in Fig. 28.

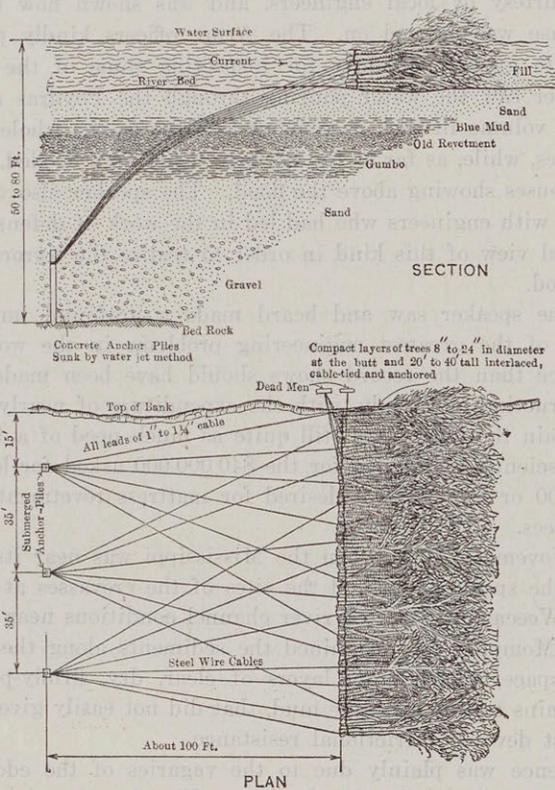


FIG. 28.

A few weeks later the speaker visited the river near Omaha, under the guidance of Mr. Towl, accompanied by the Assistant Chief Engineer of the Burlington Lines and a representative of the Woods Brothers, and was deeply impressed with the importance of what they were doing, particularly with their method of anchorage by old steel cables to concrete piles sunk by water-jet far below possible limits of erosion, the top of the anchor piles being sunk about 50 ft. below the normal bed of the river in the short space of 5 min.

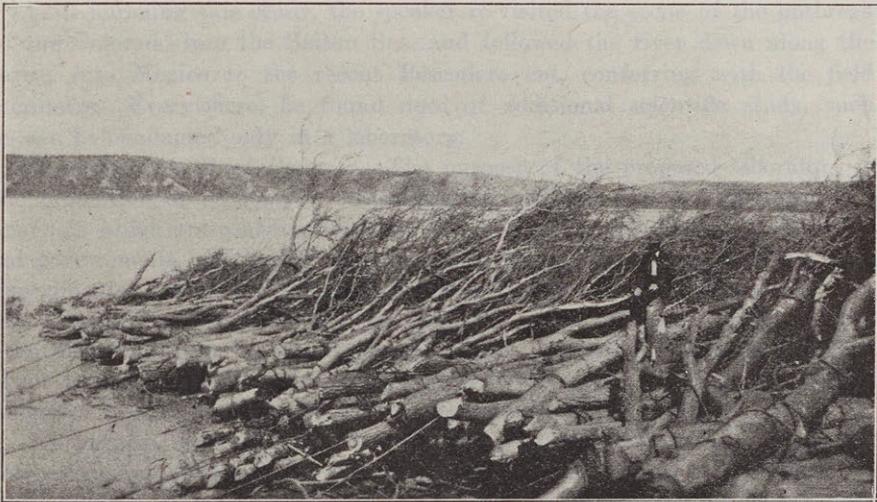


FIG. 29.—A TYPICAL WOODS BROTHERS RETARD.

The following table shows the results of the tests made with the various models of the spillway gates. The first column gives the name of the model, the second column the coefficient of contraction, the third column the coefficient of velocity, and the fourth column the coefficient of discharge. The values of the coefficients of contraction and velocity are given for the various depths of the water above the gate, and the values of the coefficient of discharge are given for the various depths of the water above the gate. The values of the coefficients of contraction and velocity are given for the various depths of the water above the gate, and the values of the coefficient of discharge are given for the various depths of the water above the gate.



FIG. 10.—SPILLWAY GATE MODEL.

The following table shows the results of the tests made with the various models of the spillway gates. The first column gives the name of the model, the second column the coefficient of contraction, the third column the coefficient of velocity, and the fourth column the coefficient of discharge. The values of the coefficients of contraction and velocity are given for the various depths of the water above the gate, and the values of the coefficient of discharge are given for the various depths of the water above the gate.

*Bank-Heads.*—Later in the year, solely for the purpose of obtaining additional information about river-bank protection, the speaker visited the U. S. Engineer office at Kansas City, Mo., and had a long conference with G. S. Haydon, M. Am. Soc. C. E., U. S. Assistant Engineer, who had studied these problems for nearly twenty years and who displayed many maps of the Missouri, from Sioux City, Iowa, to the Mississippi to show what had been done at various places, by various methods of bank protection, and for improvement of the navigation channels. He told the speaker about the vagaries of scour by eddy currents, the rapid undermining and sinking by scour, of boats wrecked in the sand, and so much about unsuccessful experimentation in building hurdles and spurs which soon were wrecked, that the speaker was again impressed with the need of a laboratory in which such experiments could be conducted with models, under controlled conditions, and on a more economical scale.

Still pursuing this study, the speaker re-visited the scene of the outbreak of the Colorado into the Salton Sea, and followed the river down along the levees into Mexico to the recent Pescadero cut, conferring with the field engineers. Everywhere, he found need of additional scientific study, such as can be conducted only in a laboratory.

*Economy the Chief Purpose.*—The purpose of the proposed laboratory is the promotion of economy in expenditures for flood control and navigation channels which are continually being asked from Federal, State, and Municipal governments, and to aid in forwarding, step by step, in connection with experiments on pieces of full-sized structure in the river, the ultimate attainment of the much desired channel from St. Louis to the sea; and possibly even ultimately lowering the flood-plain of the Mississippi to such a level that lower levees will be more secure, or even to the point where levees will no longer be needed, although both these desiderata may be a long way off.

Its purpose is very different from that of merely providing a place for the recreation of scientists and in which they may have the pleasure of making new discoveries and writing new treatises. In discussing this laboratory with Senator Ransdell and other friends interested in the great river and harbor problems of the Mississippi Valley, there has been no thought of creating a new scientific bureau in the Government with this laboratory as a center. The only purpose has been to find a home in some existing bureau, on land now owned by the Government, for a one-story building within which should be built a few large pieces of testing apparatus, to be under the custody of some one engineer or physicist of high scientific training, assisted by two or three young engineering graduate students, one or two mechanics, and one or two laborers, somewhat as is done with the great tension and compression testing machines in the U. S. Bureau of Standards, or the Emery testing machine at the Watertown Arsenal. The staff and employees of this hydraulic laboratory need not be more than ten while operating at a maximum, and many problems could be solved with half that number.

For economy of construction and operation, alongside the tank designed for river-flow experiments, the speaker has placed a parallel tank, somewhat

as has been done at the most noteworthy river-control laboratories abroad—at Dresden, Karlsruhe, and Vienna—which can be used for experiments on discharge over dams, siphon spillways, submerged weirs, fall increasers, energy absorbers, etc., all fed by the same pumps as the river channel, and with the same regulators, and stilling devices, and with their discharge measured in the same basin, and by the same Venturi meters.

In the economic design of such engineering structures, of the enlarged sizes and depths required in recent years, there is great need of more data, which are nearly always beyond the capacity of such laboratories as the engineering schools can afford, but can be obtained economically by this combination of river tank and weir tank in parallel.

It is unfortunate that, in some fields of engineering design, there are still no other data than those derived from little orifices, from 1 in. to 1 ft. in diameter, when designing sluiceways 30 ft. deep and 40 ft. across.

There are also certain tests needed by the naval engineer, in the design of boats, torpedoes, etc., for which this tank, in which a large current can be kept flowing in a circuit at constant speed, would be very useful.

The great wind tunnels at the National Laboratory of Aeronautics at Dayton, Ohio, and the wind tunnels of the U. S. Bureau of Standards, are proving useful in obtaining a great variety of important data on resistance of sundry objects and shapes to currents of air. A similar line of experiments with precisely controlled currents of water could be made with great advantage in this proposed tank.

There are many important problems, in the economics of engineering design, to keep this river apparatus busy for five or ten years, and there is ample scope at the same time for an associated group of engineers working on the rivers and harbors of the United States, first collecting data now buried in various offices, and next making new observations along the rivers, almost anywhere between Sioux City and Port Eads, with particular activity at times of high water and low water, and with frequent interchanges between the laboratory staff and the field staff.

There are studies and comparisons worth making about the strange hydraulic laws that, on one river, will build a deep sand bank behind a simple wire fence used as a current retard, and, on another river, strongly built retards of fascines and wattles, supported by deeply driven piles, are quickly destroyed. There was ample precedent on smaller rivers to lead the original Mississippi River Commission to expect good results from the relatively light, cheap structures it proposed for training the current to deposit its load of sand, which structures were quickly destroyed.

To-day on the Min River, in Soo Chow Harbor, China, some American engineers are guiding the tidal current to form a new channel and deposit a high bank of silt behind a fragile permeable dike of slight bamboo poles set up in the sand, with a few cross-poles wattled in between. Where the flood current attacks the shore on the Hoang Ho, the Chinese, guided by the experience of centuries, having no timber, deflect it by earthen spur-dikes or groynes, armored with a relatively small mass of stone at their ends, which

point down stream at about  $30^\circ$  from the perpendicular, and collect sediment in the corners above and below, although in other parts of the world such structures would seem to violate the common rules of practice.

In all these things there are reasons which the laboratory will help to find.

*Location and Direction.*—It has seemed to the speaker wise to establish this laboratory in Washington, instead of at some point in the Mississippi Valley, because for best results it should be in a scientific atmosphere, where the Director will meet and have counsel with other scientists, and where it can most conveniently help the various engineering and scientific departments of the Government.

It requires a man of rare quality for Director, one trained as a physicist, who knows about surface tension and colloids, and who can work with differential equations. At the same time he must have a love for the "great outdoors", and something of the intuition of an old-time river pilot for seeing through muddy waters, and he must be able to extract and absorb information from other men.

Among the reasons for selecting Washington, is the usefulness of such a laboratory to other Departments of the Government, such as the Reclamation Service, the Hydrographic Department of the Geological Survey, the Department of Agriculture, and naval designers. It would also be useful to the Army engineers engaged on river and harbor work, and would be convenient of access to the Engineer School. Experiments for some of these Departments could be conducted in the weir flume while the river flume was being arranged. All could work in harmony and co-operation for the common good, just as we now see officers and men from Army, Navy, and elsewhere co-operating in the various laboratories of the Bureau of Standards, which more and more is coming to be the great National Physical Laboratory.

In England the speaker was interested to find the great naval tank for experimenting on the laws of resistance to the motion of ships, in the National Physical Laboratory, with the Royal Society acting as counsellor.

During the summer of 1922 the Department of Agriculture has sought the facilities of the small hydraulic laboratory of the University of Iowa to conduct some experiments on the flow of water in pipes, and the speaker is informed that a few years ago the same Department carried on some experiments on the discharge of drainage channels, that could have been made in far less time, and with greater precision and detail in the proposed laboratory.

One of the preliminaries in the design of the great flood detention works on the Miami River near Dayton, Ohio, was to engage a professor from the University of Iowa to build a small hydraulic laboratory in which to work out sluiceway problems.

There are many important problems in which this laboratory could be useful to civilian engineers, when not in use by the Government, just as many important tests of the strength of structural materials were formerly made on the great Emery testing machine at the Watertown Arsenal, for outside parties.

Obviously, the laboratory must be convenient to a large amount of electric power for driving the pumps, for occasionally there may be a few hours in the course of the year when as much as 1 000 h. p. may be required.

A water supply circulated by pumps is preferable to a supply drawn from a river or reservoir. One advantage of this is that the temperature of the water can be controlled, another is that any desired mixture of particles in suspension can be maintained, and still another is that the precipitation of extremely fine particles, which may be in a state of colloidal suspension, by the addition of chemicals can then be studied, and perhaps much knowledge gained of why some earths are so much more slippery than others, or their angle of repose so lessened that river banks and dams have disastrous slides.

*Measure of Values Involved.*—The total cost of construction and maintenance of the proposed laboratory would be almost infinitesimal in comparison with the cost of the work carried on by Federal, State, and Municipal Governments. Its teachings would be useful in economizing designs, lessening maintenance cost, safeguarding the purpose to be accomplished, and obtaining far greater benefits than contemplated by present methods. It may at least be hoped that ultimately new designs may be worked out that will bring greater navigable depths, and that ways may be found to lower the flood heights by creating greater delivery capacity in the channels.

Altogether, to date, the United States Government has expended more than \$100 000 000 on the improvement of the Mississippi River, and in 40 or 50 years has protected by revetment only 100 out of nearly 1 000 miles of caving banks. The work of bank revetment was actively begun 30 years ago.

More than \$16 000 000 has been expended on the South Pass entrance to the Mississippi alone, without yet getting it to stay open so that a pilot will take a big ship through.

One of the latest Acts of the 67th Congress was the appropriation of \$10 000 000 to be expended in improvements on the bed and banks of the Mississippi between St. Louis and the Head of the Passes.

In addition to expenditures by the Federal Government, which, theoretically at least, are for the improvement of navigation, the States along the river, the Drainage Districts, and the individual owners are said to have expended, in the aggregate, still larger sums on the levees. The States and Drainage Districts are still contributing about as much money for levee building as the Federal Government.

It should also be kept in mind that many of the levees are not permanently secure until the bank in front has been revetted, at an additional cost, at present prices, of about \$60 per ft., or \$300 000 per mile. (The pre-war cost averaged about \$35 per ft.)

About \$10 000 000 has been expended for improving the navigation of the Missouri River between Kansas City and St. Louis; yet hardly more than a beginning has been made in stopping caving banks and shifting channels.

Meanwhile, the old lines of light-draft steamboats have practically disappeared from its surface, although some are said to be deeply buried in its mud.

The farmers of the Lower Mississippi Valley are now urging their respective States and the Federal Government to join in expending the \$40 000 000 estimated to be necessary to complete the levees to the height long ago prescribed by the Mississippi River Commission. When all these levees have been completed to this full height, their existence will be insecure until at least \$200 000 000 additional has been expended on revetment work to protect the river banks against erosion on but little more than the total length of concave sides alone. If only 600 miles are revetted, the cost at \$60 per ft. would be at least \$180 000 000. The report of 1909 on a 14-ft. channel\* quotes the survey of 1892 as showing 906 miles of caving banks, including both sides but excluding islands, in the 885 miles measured along the mid-stream length of the river. Some other estimates show nearly 1 000 miles where revetment may be needed ultimately, and sometimes, although rarely, revetment has to be replaced; but even if the total is only about 600 miles, 180 000 000 is a big enough figure for present argument.

For some years past, revetment has progressed at the rate of about 3 miles per year; at this rate, it would take 300 years to complete this 900-mile job, and, if one wants to hurry it, there is a limit to the rate at which willows suitable for mattresses can be grown.

Even after all that vast sum (\$40 000 000 for raising levees and \$200 000 000 for revetting banks) has been expended, the agricultural interests of the Valley will not be secure against crevasses like those which happened in the 1922 flood at Weecama, about 6 miles above Natchez, on the opposite side; or that of Poydras, 5 miles below New Orleans; or like those which were threatened at Stanton Plantation, across the river from Poydras; or that threatened at Tunica, about 20 miles below Memphis; and at sundry other points which were off the line of the proposed revetment, on the levees guarding the vast Yazoo and Tensas Basins.

*Object Lessons of the Unexpected.*—Although during the extraordinary high flood of 1922 there was not a single crevasse in the 1 400 miles of river bank up stream from the Weecama crevasse, near Natchez, there were many near-crevasses where there would have been damages running to tens of millions of dollars, except for the energy with which thousands of men responded to the alarm and hastily erected temporary safeguards. A few object lessons may be cited of unexpected happenings, and of other things which came near happening, all of which prove the importance of this problem and show the vastness of the money values involved. There was the threatened crevasse at Tunica, described by Mr. Dabney,† which was outside the lines of work of the Mississippi River Commission, far away from the river shore, and on a back channel that ran through the trees, across the neck of a big bend. This was near the head of the vast Yazoo Basin, and a break here might have added 5 000 sq. miles to the flooded area, and \$25 000 000 to the schedule of damages.

The Weecama crevasse, near Ferriday, about 10 miles up stream from Natchez, is another good illustration of the happening of the unexpected.

\* Report, Mississippi River Commission, 1909, p. 46.

† See p. 1150.

This was far from the main river, along the lines of Lake Concordia, an abandoned channel of the river left years ago by a cut-off. The speaker was told that no one expected serious trouble there because the levee was a mile back from the strong currents of the main river, but the break came with such suddenness that nothing could be done by those living near except to move out in a hurry. The crevasse originated in a sand boil which enlarged rapidly until about 40 ft. of the levee fell into the hole, after which it widened at the rate of several hundred feet a day, until, at the time of the speaker's visit, it was  $\frac{3}{4}$  mile wide, and a territory of 1 000 sq. miles was submerged by the current, estimated roughly at 200 000 sec-ft., or about equal to the whole flow of the St. Lawrence River.

At Myrtle Grove, 35 miles below New Orleans, the crevasse of 1922 is said to have occurred in the middle of the night, and to have been due to a sand boil.

At Stanton Plantation, about 6 miles below New Orleans, nearly opposite the Poydras crevasse, at the height of the flood, the speaker found a large number of men hastily building a section of new levee back of the threatened part. This was on a convex bend, well shielded by a grove of willows on the up-stream side, and no trouble was expected. The river here was about 80 ft. deep. Fortunately, the flood subsided before it had cut entirely through the old levee.

*The Values Threatened.*—The great extent of these threatened fertile bottom-lands is not commonly realized. The total area of the six lower Mississippi Basins is nearly 30 000 sq. miles, or 20 000 000 acres, subdivided as follows:

St. Francis Basin.....	6 706 sq. miles
Yazoo Basin.....	6 648 " "
White River Basin.....	956 " "
Tensas Basin.....	5 370 " "
Atchafalaya Basin.....	8 109 " "
Pontchartrain Basin.....	2 001 " "

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29 790 sq. miles

Although this land is now only partly drained, drainage has been going forward rapidly for 20 years and only the assurance of protection is needed soon to bring substantially all under cultivation. A moderate estimate of its value when drained is said to be \$100 per acre, and at this rate, 5 000 sq. miles, in the Yazoo Basin alone (allowing that reclamation of one-fourth the whole area is impracticable) has a potential value of more than \$300 000 000.

In all these basins there are present or potential farm values of nearly \$2 000 000 000, and the flooding of any one of them by a crevasse at its upper end, like that which came near happening at Tunica, with the driving of substantially all the inhabitants from their homes, might readily cause damages of more than \$10 000 000 or \$20 000 000, although the waters receded rapidly enough to permit a late partial crop, as around the Ferriday crevasse

in May, 1922. Sometimes, floods stay up so late that practically the farmers' whole year's work is lost.

There is also a large loss in fertile land year by year by the levees having to be set back, about 500 ft. from the old location which is threatened. The new levee at Weecama thus sacrificed a strip about 1 mile long and 1 000 ft. wide, or perhaps 100 acres of extremely fertile land. All along the river, sections of new levee have been set back, showing that the first cost is not the only one.

The damage that can be caused by such a break as threatened in the season of 1922 at the upper end of the Yazoo Basin, at Tunica, is beyond exact computation, and can hardly be realized by one who has not seen a flow larger than that of the Niagara or the St. Lawrence River pouring through a crevasse nearly a mile wide and flooding tens of thousands of acres so that only the tops of the houses appear above the surface of the water.

It is a startling fact that, after all the work proposed to be accomplished in topping out levees and revetting even 600 miles of caving concave banks, at this cost of, say, \$230 000 000 has been carried out, breaks like those threatened at Tunica and Stanton, or like those which occurred at Weecama and Poydras, may still come, for three out of four of these localities were off the line of the proposed revetment, and even revetment has sometimes succumbed to wear and tear and the scour of the flood.

*Other Expensive River-Training Problems.*—The great Imperial Valley of California, with untold millions of present and prospective value, is still threatened by the Colorado River below Yuma, Ariz., which, although diverted temporarily through the recent Pescadero cut into a broad, low-lying area which will be filled rapidly by sediment unless extensive new river training is undertaken, is likely in the course of 15 years to shift its channel and perhaps repeat the break into the Salton Sea, the closing of which cost the Southern Pacific Railroad \$1 500 000.

The State of California, in partnership with the Federal Government, is now expending several million dollars on a new flood-relief channel for the Sacramento Valley, and both the Sacramento and the San Joaquin Valleys, with their tributaries, present a variety of extremely important problems of erosion, transportation, and deposition of sediment, which the proposed laboratory could greatly aid in solving.

New Orleans, in the past few months, has been discussing the old problem of a short cut to the sea, through a spillway about 5 miles down stream, estimated to cost \$3 000 000 to \$5 000 000 for the immediate structure, and additional sums for the appurtenances and damages along its channel to the sea.

After great sums have been expended for the construction of the works just described, the problem of maintenance remains. For example, the Federal Government now expends more than \$1 000 000 a year in the upkeep of its river-training structures along the Mississippi, and the speaker has been told that the Missouri would now require several million dollars to put back

into as good condition as formerly, the river-training works which had to be neglected during the World War.

Several pages could be taken up by continuing this inventory, citing active calls for many more millions, but enough has been stated to show that a laboratory costing \$200 000 in apparatus and the maintenance of a staff of 5 to 10 men, is extremely small in comparison with possible savings.

Apart from river-training problems, such as levees, revetments, and channel maintenance, there are the problems of training tidal currents. Many harbor inlets are obstructed by deposits of drifting sand, along the coasts of New England, the Gulf of Mexico, and the Pacific Ocean. There are also urgent problems of seashore protection, in the economic design of which a laboratory such as that now proposed would be of great assistance.

*Mississippi Not Saturated.*—Returning to the Mississippi, it now seems certain that Capt. Eads and others who judged conditions mainly from the practical viewpoint of the field, were mistaken in thinking that the water of the Mississippi is ever saturated with sediment. The quantity that can be retained in suspension probably depends almost entirely on the size of the sand grains, the velocity, and the internal motions caused by irregularities of bed and banks. The Yellow River, in China, carries 8 and 10% of sediment by weight at mid-depth and near the surface in the peak of a flood, which is more than double the highest percentage reported distributed broadly in the Mississippi. Some Arizona and other Western streams carry similar high percentages. The speaker's observations on this mud-laden Yellow River tended to disprove the oft-stated idea, that there is a slow-moving stream of fluid mud or sand, 1 or 2 ft. deep, flowing along the bed. He found plenty of sand waves, with high steep down-stream slope, traveling slowly, but no sign of a separate stratum of flowing mud.

The traveling of sand waves along the river bed is a matter needing investigation. Perhaps such waves can be guided and induced to lodge where they will do no harm, somewhat as snow fences along a railroad guide the snow into drifts.

Plainly, also, much useful information is yet to be obtained about "boils" and vortices, and how to control them or put them to beneficial use in the transportation of sediment; and in all this work the laboratory, together with observations on the river, will help.

*Filling Swamp with Sediment.*—Centuries ago, in China, near the old mouth of the Yellow River, large tracts of salt marsh were raised above the level of the sea and made available for agriculture by flowing a bed of silt from the river over them. A long dike only a few feet high was thrown up along the outer edge of the tract, and muddy flood water from the river was then carefully let in. This flooded the ground, and in the great pool the burden of silt was laid down; then the comparatively clear water flowed onward and out through sluices to the sea. There is a large area east, south, and west of New Orleans, suitable for such experiments, although the time may not yet have come when such work will pay dividends. A better understanding of the laws of transportation of sediments will help in all such problems.

*Cut and Refill by Current.*—Years ago the speaker learned of the remarkable way in which some of the smaller rivers of the Rocky Mountain region dig themselves in during a flood and refill the bed to the former height as they subside. Recent observations show that the Colorado River near Yuma presents as fine an example of this as could be desired. In his studies of the Yellow River the speaker was on the lookout for such phenomena, for it seemed to him that if the rules could be established, the engineer could direct these “great sources of power in Nature for the use and convenience of man.”

S. L. Rothery, Assoc. M. Am. Soc. C. E., has given an interesting account\* of the utilization of these forces in helping to dig the great Pescadero cut.

By using these principles, at a cost of about \$87 633, of which dredging cost about \$34 172, other work that would have cost more than \$1 500 000 was postponed indefinitely.

The dredged channels, of about 200 ft. total width, and 8 ft. depth, were quickly enlarged by scour to a width of about 500 ft. and a depth that carried safely a flood of about 100 000 cu. ft. per sec. In conception and execution, this was a good engineering work. The speaker had been planning something of this kind in China, but Mr. Cronholm and Mr. Carberry have forestalled him, and he rejoices at their success.

Further study in laboratory and field will disclose the rules for doing this kind of work economically in many places, and thereby enable the creation of channels that would be beyond the economic reach of steam shovel, drag-line, or dredge. Additional cross-sections of the Colorado near Yuma, recently obtained, show that river bed following closely the same rules.

For the alluvial, non-coherent, sands of China the speaker found that, with mean channel velocities of more than 3 ft. per sec., cutting rapidly increased, and that by the time the mean velocity had increased to 7 or 8 ft., the river bed was deepened so fast, by the sand being taken into suspension, that the velocity could not increase. The speaker's observations, however, were but a beginning, and it needs laboratory experiment with many varieties of material and various sizes of grain to determine these laws and make them convenient for use by the engineer. In the laboratory design, Fig. 18, the object of the muddy water return conduit and the facility for changing the inclination of the flume, was to afford a good range of experiments on this important matter.

*River Training at Bridges.*—Great Rivers, like the Lower Mississippi, the Lower Missouri, the Platte, the Hoang Ho, the Yangtse, the Ganges, and many others, flowing through broad alluvial deposits, present another interesting field in which the laboratory may point the way to shortening bridges over such rivers, in some cases, by more than half. The speaker ventured to design control works, about two years ago, for shortening the length of the proposed new Yellow River Bridge of the Peking-Hankow Railroad from 2 miles to less than  $\frac{1}{2}$  mile, and had abundant proof that this was entirely practicable.

\* *Proceedings, Am. Soc. C. E., April, 1923, p. 671.*

English engineers in India have greatly lessened the length of their recent bridges by training the river into a narrow course between "Bell-Bunds," so named from Mr. J. B. Bell, the distinguished engineer, who first devised them. A very interesting book\* on this subject by Sir Francis J. E. Spring, M. Am. Soc. C. E., one of the most experienced of the British engineers in India, relates mainly to this matter of training rivers at bridge crossings and at low dams on sand foundations for the diversion of river water into the great irrigation canals. Fig. 30 is one of Mr. Spring's designs for one of the most difficult bridge sites in India.

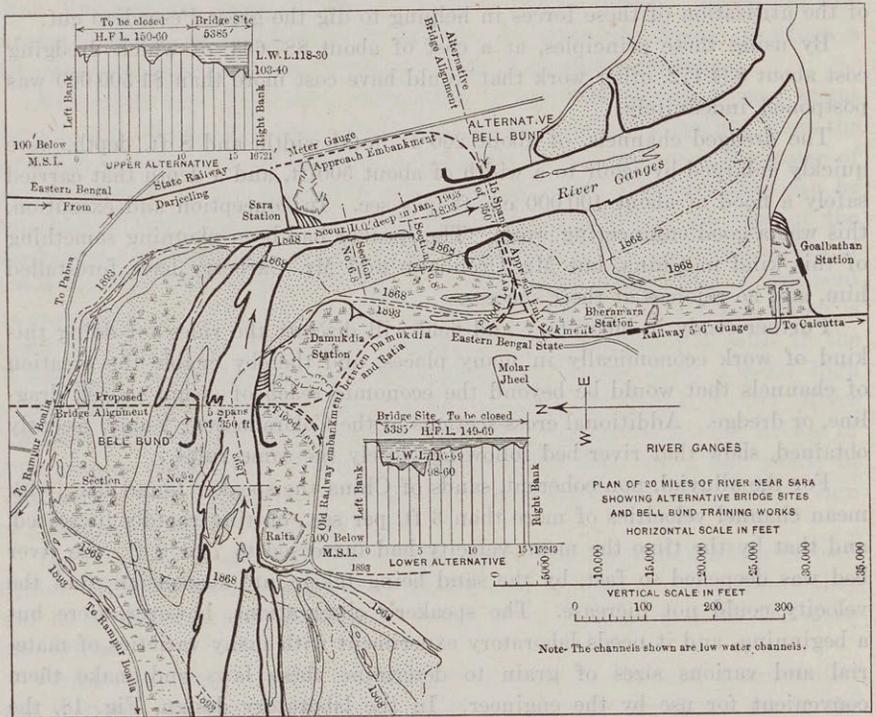


FIG. 30.

*Joint Study in Laboratory and River.*—The relation of the proposed laboratory to river training should be understood clearly as that of an instrument to be used in conjunction with observations on the river itself, and as a means of controlling various factors governing the action of water in erosion, transportation, and deposition of sediment, can be studied separately and the conditions repeated at will. The confusion of causes and other obstacles and limitations found in attempting to observe active, brief transitory flood phenomena on the river, would thus be removed.

The method of experimenting only with the full-sized specimen in the river itself has been going on somewhat spasmodically along the Mississippi

\* "River Training and Control by the Guide Bank System", Govt. Printing Office, Simla, 1903.

and Missouri and elsewhere for about 50 years, and it now seems high time to economize and to extend and supplement these field operations by laboratory experiments.

To make still plainer the idea of using the laboratory chiefly as a tool for supplementing studies in the field, it is suggested that the best way to begin these studies, and plan the sequence of laboratory studies in their order of importance, would be for the Director and some of his helpers, while the laboratory was being built, to organize a systematic search through the archives of the several District Offices of the U. S. Engineers on river and harbor work, and in the offices of the State Levee Boards, in order to collect all the data that can be found on the physics and hydraulics of these rivers, and to gain the friendly counsel of the officers now and formerly in this service, and particularly of the able staff of U. S. Assistant Engineer; many of whom have had the great advantage of continuous opportunity for observation and contact with these problems year after year.

The speaker is assured by the Chief of Engineers that there are many unpublished data which would be useful in a comprehensive study. It appears to be a rule imposed by Congress that the Chief of Engineers must not include technical discussions in his annual reports. The annual engineering reports, dealing chiefly with details of disbursements authorized by Congress, are most rigorously condensed.

After the Director and his staff had made this data survey they should re-read the report on the physics and hydraulics of the Mississippi by Humphreys and Abbot and the recent admirable "Résumé" by Major Eveleth Winslow, the scattered technical papers in the *Proceedings* of the Navigation Congresses and the Engineering Societies, and the excellent books by Van Ornum, Thomas and Watt, Col. C. McD. Townsend, U. S. A. (*Retired*), and Professor Hubert Engels, and examine the Congressional documents and reports of commissions relating to these rivers. Then these laboratory men would get a better idea of their problems by some weeks of voyaging along the river, examining the sites of cut-offs, back channels, and sloughs, stopping for hours at typical suction eddies, boils, sand-bars, and caving banks, sampling the strata, making sediment determinations and mechanical analysis of sands, etc., and testing various current meters and sounding apparatus at typical eddies, vortices, boils, and traveling sand waves, repeating these visits at widely different stages, and particularly visiting recent crevasses, and points where crevasses were dangerously near in April and May, 1922. Incidentally they might try to find out what becomes of the sand grains traveling down the river in abundance and used for mortar sand in the up-river cities, although hardly anything so large as  $\frac{1}{100}$  in. in diameter can be found below New Orleans. Doubtless, these are coarser in the upper river, and no explanation is yet at hand as to what becomes of the coarser sands for they are not found below New Orleans or in the Passes at the mouth. Most of the material in sand waves and crossing-bars is believed by those familiar with the river to be of local origin, coming from the caving banks immediately up stream, but where do the sand waves go, which have traveled down stream all the time

since the glacial epoch? It seems to be hardly possible, as contended by old Italian authors, that pebbles are worn to sand, and sand grains to silt.

After obtaining this foundation of records and fresh personal contact with land and water, the Director would find the most important laboratory problems to be the fundamentals, such as the study of erosion velocities for different materials, the trace of currents around obstacles, a continuation of the Gilbert experiments with grains of small sizes, the laws of sedimentation, the behavior of colloidal material, and the action of mixtures of under-currents of sea water in precipitating sediments carried by fresh water.

It would probably be found that data from experiments on European rivers were largely inapplicable to river training along the Missouri and Mississippi because of the much larger grain size of European sediments and their less adhesive quality. In the speaker's few observations abroad he has noted many important differences.

*Alternate Work in Field and Laboratory.*—The great advantage of the laboratory is that in it one can create the special condition which he desires to observe regarding velocity of current, kind of bed material, or angle of impact, and can vary the conditions and watch the effect of modification in a way that cannot be done in the field.

A few barrels of river sand (or a carload), from any desired locality can be transported to the laboratory and spread over the model river bed.

By one variant after another the investigator can form conclusions, whereas on the river itself during a great flood there is scant opportunity for studying the precise relation of cause and effect between current and sand grain. After all, the problem may be found to be mainly one of the little things, of single sand grains and of molecular forces, rather than of the dynamics of the great mass.

The great floods which threaten widespread damage come only about once in 10 years, and it will nearly always happen, as in the flood of 1922, that the engineers competent to make scientific observations will be busy night and day in strengthening the levees. The speaker asked the Chief of Engineers, U. S. A., if, during the recent great flood any observations had been obtained which would show whether the Mississippi, like the Yellow River, dug its bed deeper during a flood and refilled it with sediment as the waters subsided and velocity decreased. He answered, "no, because the entire staff then had its hands full hastening the work of levee protection."

It is presumed that, during the past 40 years, many data of that kind have been obtained, but probably a new systematic study would call for supplementing the present data by new surveys, soundings, or borings here and there, such as could be done by one small party. After the lay of the land, etc., had been learned, emergency work could be organized to cover critical points in time of flood.

Fortunately, in a great flood of about 40 years ago, there happened to be in the field half a dozen survey parties mapping the river. Their work was interrupted by the flood, and with great wisdom, as described by the late J. B. Johnson, M. Am. Soc. C. E., who was in charge of one of these parties,

they set to work with increased energy to collect all possible engineering data; but it seems that during the years that have elapsed, this happy accident of opportunity for data collecting in flood time, has not been repeated.

As to the relations between the small model and the great river, or the effect of scale of model, velocity of current, and size of grain as affecting erosion, suspension, transportation and deposition of sediments, the dictum of the mathematician need not be accepted without convincing proof from other sources, because, with the arrangements proposed, in which a group of field observers work hand in hand with the laboratory group; with frequent interchanges of personnel, one could soon confirm or readjust the scale relations that already appear to have been worked out satisfactorily in the river-control laboratories of England and Germany, as set forth particularly in the works of Professors Osborne Reynolds, Hubert Engels and others, as well as in Professor Van Ornum's account of the laboratory at Berlin.

The speaker stated before the Senate Committee, that the steamboat pilot on the river and the scientist in his laboratory each has certain advantages in his point of view, and that much of the river-training work in America has been of that quality that might be expected to be produced by a committee of steamboat pilots without special training in exact science, and that it is now high time for more of science.

There is no doubt that the Army engineers have devised the very best revetment and can put it down more skilfully than any other group of men in the world, but the problem remains of finding a way to safeguard 600 miles of river banks and levees at a less cost than \$300 000 per mile, and a way to maintain navigation channels more than 6 ft. deep without continuous dredging. A laboratory like those abroad, but bigger and better, would help them.

Although the speaker has read and re-read much that has been printed in English on river training, it has seemed that the present state of scientific attainment in river science resembles that attained in chemistry before sensitive balances were used—or in electricity prior to the use of the "c. g. s. units," and that diametrically opposite opinions can be found strongly expressed by equally eminent authorities on almost every important subject. It would seem that engineers are still in the stage of opinion evidence, and plainly need more precise weights and measures in laboratory and field to lay the foundations of a real science of river hydraulics.

Not many years ago, the builders of highways had little or no use for scientific refinements or for a highway laboratory, and methods and opinions varied in proportion to the number of county commissioners, but, within the past few years, the laboratory has become widely recognized as of the utmost importance in the economic building and maintenance of State and city highways, and so it will be found with the studious use of the laboratory in close association with observations and experiments on the river.

#### EXPERIMENTAL WORK IN TRAINING THE MISSISSIPPI

As a result of costly experiments, the general line of effort in training the Lower Mississippi appears to have been changed radically, about 30 years ago,

by ceasing to attempt to train the river to do its own digging over the bars and shoals by narrowing the wide places with permeable dikes behind which deposits of sediment would accumulate, and concentrate the current in one main channel.

For many years the efforts appear to have been confined almost solely to holding the caving concave bank where it is found, by using revetment, the river being left to follow its own inclination along the convex shore and within the broad areas found in straight reaches and reversals of curvature, permitting it to shift its channel between shoals and islands, almost without restraint. Meanwhile, dredges have been adopted on an extensive scale for maintaining through the bars channels of sufficient depth for the small present-day steamers.

The original policy remains unchanged as to preventing cut-offs and fixing the main channel substantially in its present location, and of avoiding any attempt to straighten the river or shorten its course, the reason being that each cut-off quickens the velocity of the current, starts new banks caving, and thus tumbles into the river new masses of débris to form bars, fill channels, and plant snags.

When the Mississippi River Commission made its first report, 43 years ago, the members (one of whom was Captain Eads, and all of whom had long experience with this river), although differing on some points, agreed in a clearly defined policy as to what works were needed to improve navigation and carry out the purposes of the Act of Congress of June 28, 1879, which were, in the words of the Act:

"To mature such plan or plans and estimates as will correct, permanently locate, and deepen the channel and protect the banks of the Mississippi River; improve and give safety and ease to the navigation thereof; prevent destructive floods; promote and facilitate commerce," etc.

The opinion and policy of the members of the Commission may be summarized in the following sentences taken from their report:

"The bad navigation of the river is produced by the caving and erosion of its banks, and the excessive widths and the bars and shoals resulting directly therefrom.

\* \* \* \* \*

"It would seem, therefore, that the plan of improvement must comprise, as its essential features, the contraction of the water-way of the river to a comparatively uniform width, and the protection of caving banks, \* \* \* bad navigation invariably accompanies a wide low-river water-way, and good navigation a narrow one.

"The work to be done, therefore, is to scour out and maintain a channel through the shoals and bars \* \* \* where the width [of the river] is excessive, and to build up new banks and develop new shore-lines, \* \* \*

"It is believed that this improvement can be accomplished below Cairo by contracting the low-water channel-way to an approximately uniform width of about 3 000 feet, \* \* \*

"It is believed that the works estimated for in this report will create and establish a depth of at least 10 feet at extreme low stages of the river over all the bars below Cairo, \* \* \*

"It is the opinion of this Commission that, as a general rule, the channel should be fixed and maintained in its present location; and that no attempt should be made to straighten the river or to shorten it by cut-offs.

"The borings \* \* \* made in 1879 at New Madrid and Plum Point, \* \* \* those of more recent date at Memphis and Helena, \* \* \* as well as those near Lake Borgne, reported by the levee commission of 1875, and others made along the proposed line of the Fort Saint Philip Canal, and the artesian well sunk at New Orleans, all furnish concurrent evidence of the yielding character of the strata forming the river-bed. This evidence, taken in connection with the fact that deep water is found in all the bends of the river where the width is not excessive, \* \* \* point to the conclusion \* \* \* that there is no extensive stratum of material capable of resisting erosion and preventing the river from deepening its own bed. In exceptional localities, where the material is too tough, or the gravel too heavy for removal by scour, dredging may have to be resorted to as an auxiliary, the depth secured by this means being maintained by the works erected for narrowing the stream.

"Experience \* \* \* justifies the belief that the requisite correction and equalization of the transverse profile of the stream, by developing new shore-lines and building up new banks, may be made chiefly through, the instrumentalities of light, flexible, and comparatively inexpensive constructions of poles and brush, and materials of like character.

\* \* \* \* \*

"The closure of deep channels or low-water chutes, with a view of confining the flow to a single passage, may require substantial dams of brush and riprap stone or gravel, but it is believed the lighter and less costly works will generally suffice."

*Revised Conclusions of Mississippi River Commission.*—A few years of expensive experience taught the members of the Commission that they had greatly underestimated the forces with which they had to deal.

It is of interest to note that, all through the early reports of the Commission, the improvement of navigation is the fundamental idea, and almost nothing is said about levees; for at that time and for long afterward it was considered that those who owned rich agricultural lands should bear the cost of protecting them against flood. It is interesting, as one follows the long series of Engineering and Congressional reports on the Mississippi, to note the gradual change in the respective prominence given navigation and levee construction. In the early years, navigation was almost the only motive. In later years, the emphasis is put on levee building and on building revetment for protecting the levees, in order that the sediments from caving banks might not obstruct the river bars.

It has been long recognized, and has been stated repeatedly by the engineers and the members of the Commission, that if a stop could be put to the vast quantities of debris and earth tumbled into the current year after year by caving banks, the annual up-building of bars would soon cease and dredged channels could be readily maintained.

It may be worth while to review again these early ideals, having improved navigation channels as the chief motive, and in such a new study the laboratory could be made of great service, better forms of cheap dikes and retards could be devised, and a better understanding gained of just where to place them.

In the early days of the Commission, it was believed that, by the use of these longitudinal permeable dikes of piles and brush fascines, connected with the old bank at suitable intervals, by cross-dikes of like character, the areas to

be thus reclaimed by narrowing between the banks, could be converted into silting basins, and that building them up by deposits would go on continuously through high-water seasons; new dikes and retards being built on the higher level, as growth required. Wherever necessary the newly formed bank was to be protected by a mattress revetment, or equivalent device, and the river thus held to the narrowed course.

*Experiments in Plum Point Reach.*—For proving these conclusions, and in order to obtain a better basis for estimates of cost, the Commission in 1890 selected Plum Point Reach (Fig. 31), about 20 miles in length, some 90 miles up stream from Memphis, known as one of the most difficult localities along the river, where in times of low water the depth available for navigation sometimes fell to less than 5 ft. The shallowness and the shifting channel here were evidently caused by the excessive width of the river, which for long distances was from 2 to 3 miles from bank to bank, between which were various low islands, separated by chutes which carried parts of the flow of the river.

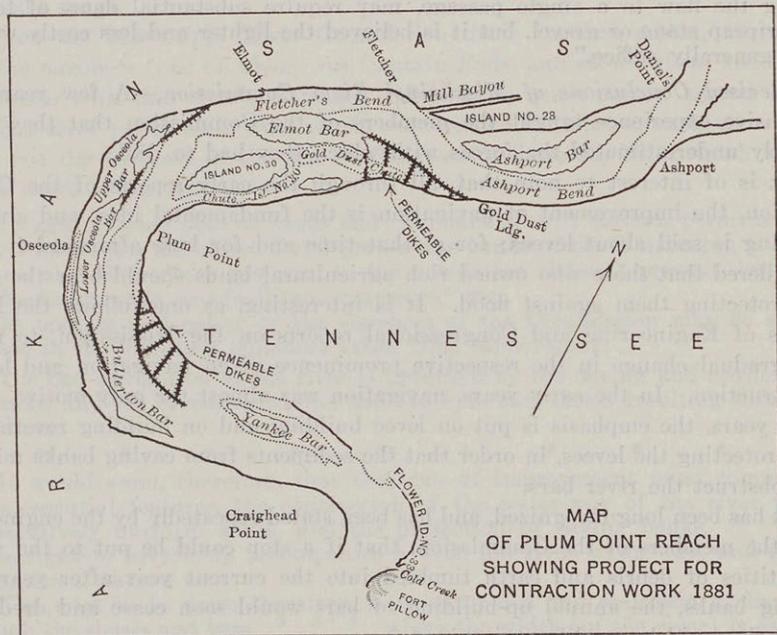


FIG. 31.

For the initial works the Board adopted a plan reported by a previous Board of Engineers on January 25, 1879, and secured, in March, 1881, an appropriation of \$600 000. This was followed by other appropriations, applied almost solely to attempts to train the river within this relatively short reach, which amounted to more than \$2 000 000 in the course of about 4 years, by which time Congress seems to have become frightened by the costs and lack

of permanence, and called a halt by limitations in the Appropriation Act of 1885.

Longitudinal dikes and cross-dikes of this light character, built in the first 2 or 3 years at a cost of hundreds of thousands of dollars, were destroyed quickly by successive floods, mainly by reason of the scouring out of the bed of shifting sand into which the supporting piles were driven. The permeable structures became clogged by a vast quantity of floating trash, uprooted trees, etc., which in some places piled up to a depth of 20 ft. against the dike and extended out several hundred ft. in front, so that a head of water and great pressures were developed. Thus a strong current was created under the base of the dike, and the support of the piles was quickly scoured out. The longitudinal direction appeared particularly to invite attack, and the scour of a deep, narrow channel along its down-stream side quickly developed which had to be guarded against by wide strong mattress work through which the piles finally were driven.

The story of these experiments, as detailed by Col. Winslow, is extremely instructive.

Structures of increased strength were gradually developed, which, although breached here and there by the flood, resisted long enough for an admirable demonstration of the original idea of the Commission, that behind such permeable barriers high banks of sediment could be built up, which would soon become overgrown with a willow thicket.

The trouble came with the quick tearing out of the permeable dikes and the great cost of providing them with a footing that could resist scour. Then they developed the triangular-frame dike and its detached pile anchorage, a very close prototype of the recently successful "Wood Brothers Retards."

The progress of this experimental work, with its failures and its successes is admirably set forth in Col. Winslow's résumé of the operations in the First and Second Districts during the 20-year period, from 1882 to 1901.\*

This work of river-bank training and upbuilding cost about three times as much as had been estimated in the beginning, and the report of the Commission in 1889 indicates more or less of a change of base, by ceasing attempts at narrowing the river while turning toward making the work of bank protection with revetment of first importance.

In other words, since that time, instead of trying to put the bank where it ought to be, in order to give uniform width of river and consequent concentration of a scouring current over the bars, which, in the state of Nature, are found mostly in straight reaches and at points of reversal of curvature and wherever the river is excessively wide, apparently the Commission now concluded that the cost compelled the abandonment of that plan and the acceptance of the location of banks presented by Nature, and that most of the works to be constructed in the future would have to be limited to protecting by revetment those parts of the bank in immediate danger of erosion and

\* *Occasional Paper No. 41*, of the Engineer School of the U. S. Army, published in 1910. Notwithstanding its modest title, this 296 page book, with its accompanying volume of plates, its clear judicial descriptions of failures and successes, forms a most instructive book on this one phase of river training. It might well be republished for wider circulation, and be put on the reference table in all schools of Civil Engineering.

caving, which parts are found along concave shores or along city fronts, selecting from hundreds of miles of caving banks the few worst places.

It was estimated that this revetment work in protecting these threatened banks would cost, for the type thus far devised and perfected, about \$150 000 per mile, and assuming that only 400 out of the 1 200 miles comprising the two banks down stream from Cairo required such revetment, the cost would aggregate \$63 000 000.

Since that time the strengthening of design and the increasing costs of labor, have brought the cost of revetment to about \$300 000 per mile, and the careful inventory of caving banks presented in the report of the Commission on the 14-ft. waterway mentions nearly 1 000 miles and estimates that perhaps 600 miles would require protection in order to hold the river in its present position, and prevent the enormous burden of earth and snags thrown into it from the caving banks, following each flood.

Although realizing that these problems of the Mississippi and Missouri are far more difficult than any studied in the European laboratories, the speaker is strongly inclined to believe that the laboratory would have helped in lessening the cost of developing the successive types of dike used in the Plum Point Reach, and that it is within the possibilities that it might now point the way to a cheap and successful section and form of permeable spur-dike with rounded end inclined to the current, by which the bank could be built up and held.

As one reads the extremely instructive accounts of the expensive experimental work in creating new banks and closing chutes at Plum Point, and notes the success of the latest development in the dike, in which a submerged triangular frame supports an inclined flexible screen of willow trees, held by a flexible cable to a detached pile, he can but note how closely this foreshadowed the recent form of the retard, and wish that the Commission might have continued its experiments further, and used a heavy anchorage sunk by water-jet below the limit of scour.

Nevertheless, the Mississippi presents its problems on so large a scale, that it may take 40 years more of experimental work of one kind and another before its solution can be confidently reached. At present we are 70 years along the time axis from the Humphreys and Abbot investigations, and it seems proper to hope to go farther in the next 70 years, if the problem is attacked earnestly and studiously in laboratory and field.

The Missouri River and still smaller streams present the most inviting opportunity to work up gradually to structures on a scale that can be used with the far greater channel depth and greater flood rise of the Mississippi; and what has been done on the Missouri in the last two or three years, with the Woods Brothers' system of anchoring their "retards," following 25 years of other experimentation, certainly promises success in training the Missouri.

On the latter river, more than 20 years ago, results were obtained in the long, gently curving reach near Jefferson City, Mo., which appear to prove abundantly the possibilities of maintaining good depth through the currents, if the river can be held to nearly uniform width. This is illustrated in Sheet

No. 4 of the map showing the condition of improvement works constructed by the Missouri River Commission in the 11 years, from 1891 to 1901, inclusive.\* The ends of the groynes there shown seem to have been gnawed off by ice and current, but, doubtless, one could soon learn how to shape the ends so that they would remain.

From reading the many reports on the Missouri, it would seem that twenty, or perhaps fifty, kinds of current retards, dikes, groynes, gabions, and bank-heads had been tried for guiding currents or protecting banks. S. Waters Fox, M. Am. Soc. C. E., has written an excellent account† of those tried in the 27 years from 1876 to 1903. Any one who will extend the clear and discriminating record given by Mr. Fox through the past 20 years, and will also compile and complete to the present the story so well told by Major Winslow about the 20 years of failures and success in the Plum Point Reach, adding the experiments at Lake Providence and other parts of the river, and will then give an account of the forms of Brownlow weeds, bell-bunds, etc., tried in India by British engineers along the Ganges and Indus, will be making a monumental contribution to river engineering, because, "it is through our failures we achieve success."

#### CHANGED RELATIONS OF NAVIGATION AND FLOOD RELIEF

The paramount idea in expenditures on the Mississippi and other rivers by the Federal Government originally was that of the improvement of navigation, under the constitutional power to regulate commerce between the States; but, within the past century—and particularly within the past thirty years—the relative importance of the improvement of navigation along the Mississippi above New Orleans has shrunk to insignificance in comparison with the demands for the reclamation of fertile farm lands and their protection from flood. It seems no exaggeration to say that to-day, up stream from New Orleans, reclamation and flood control are, in the popular view, a hundred times more important than navigation.

Under the competition of railroads, with unfair rates to and from river ports, and with their far more convenient terminals and their better facilities for receiving freight from farm or factory, and for delivering their freight directly into the warehouse whence it is distributed toward the ultimate consumer with a minimum of rehandling, trucking, breakage, and delay, the steamboat has now practically disappeared from these rivers as an important means of transportation.

From time to time there is popular agitation about restoring navigation. Examples of transportation on European rivers are cited, and rosy pictures are painted of the products of the great Mississippi Valley floating on their way from St. Louis, from Omaha, Pittsburgh, and even from Chicago, to New Orleans and to the sea, by way of the Mississippi and its tributaries. Far be it from the speaker to say this could never come, under some new method of river-bank training and control which in the future may be worked

\* Forming part of a report dated April 30, 1908, by Edward H. Schulz, M. Am. Soc. C. E., Col., Corps of Engineers, U. S. A., made to the Chief of Engineers, and published in Congressional Document No. 1120, H. R., 60th Congress, under date of December 7, 1908.

† *Transactions, Am. Soc. C. E.*, Vol. LIV (1905), p. 280.

out slowly and cautiously, step by step, with this proposed laboratory as one of the leading instruments.

The 14-ft. channel having proved beyond economic reach, because of quick refilling of dredged cuts and the enormous costs, all that now seems to be expected, or hoped for, is a channel across the bars not less than 9 ft. deep in the low-water season. The speaker has profound respect for the knowledge of the able men who have devoted years of close personal study to this river, but is far from giving up hope that, under some new departure, with the laboratory as an aid, 14 ft., or even 21 ft. to St. Louis can be had within fewer years than have elapsed since the studies of Humphreys and Abbot.

The aid to levee building by the Federal Government is on the theory that the levees will aid navigation by confining the water from spreading, thereby causing a deepening of the river channels, which gradually would improve navigation. The opposite result, namely, that the river bed would be raised by confining the water and preventing the deposit of sediment on the back land was often prophesied years ago, but less confidently in recent years.

*Depth not Impaired by Levees.*—Any unprejudiced engineer who studies the evidence must agree with the Army engineers and the Mississippi River Commission that this narrowing by levees has not been injurious to the channel depths.

Careful surveys, with thousands of measurements and comparisons of bed elevations, appear to show a slight deepening, although perhaps not yet enough to compensate for the waterway cut-off, and it may be true that this confinement has raised the height of floods.

The proportion of the whole discharge carried onward in that part of a flood spread thinly over the bottom-lands, or over low foreshores covered with willows, is far smaller than is popularly supposed, as may be readily shown by computation for a specific case. The widespread flood moving down stream, eddying around obstructions, makes a great appeal to the eye of the non-scientific observer, but the speaker has found by computation for specific cases that 80 to 90% of the flood volume was contained in the relatively narrow channel over the deep ordinary bed.

As far as definite records have been found, whatever deepening of the channel bed has been caused by this confinement of flood waters by levees has thus far caused no deepening of the river at the critical points sufficient to facilitate navigation materially.

Although the average of wide-spread surveys shows some slight deepening, it is not the depth over the broad area, but that in the narrow channel in the short course over the bars, which affects navigation, and it appears increasingly evident through the work of successive years that the only kind of narrowing which can be effective in deepening the navigation channel must be of that order originally attempted by the Commission in 1882, and suspended indefinitely because of cost and breakage until a good durable and economical form of groyne or spur-dike can be invented. Hence, the speaker's earnestness in presenting the laboratory method as an aid for developing this

much needed structure. A steamboat channel dredged through a bar is generally filled up again by the next flood; so that under present conditions and as far as the present system can be projected into the future, the maintenance of a good practical navigation channel from St. Louis to Vicksburg, or below, by dredging, becomes a never-ending labor.

The admirably complete report of the Board of Army Engineers on the proposed 14-ft. waterway from St. Louis down stream is instructive in these matters. After a long investigation, with many surveys and a review of the experience of 50 years, the members of the Board appear to have concluded that the maintenance of the 14-ft. depth of channel across the bars was not within financial possibilities.\* It was estimated that a 14-ft. channel over the bars from St. Louis to the mouth, under the prices of 1908, would cost \$128 000 000 for construction, and \$6 500 000 annually for maintenance after completion. It was concluded by the Chief of Engineers in submitting this report to the Secretary of War that an 8-ft. channel to Cairo and a 9-ft. one thence down stream, according to previous projects, "would give adequate service and would be desirable if cost was reasonable."

Surveys are said to demonstrate that the present average low-water depth between St. Louis and Vicksburg is about 35 ft., but in this case averages do not count. Traffic is controlled by the shallows of 6 ft. over the bars that comprise hardly more than 1% of the length of the steamboats' course.

*Bars Caused by Floods and Caving Banks.*—The principal trouble in maintaining navigation depths over the bars has been well understood since the days of Humphreys and Abbot. It was excellently explained, 36 years ago, by the late Professor J. B. Johnson, who gained his experience by years spent as a U. S. Assistant Engineer on the early river surveys. He made plain in several publications that during a flood the Missouri, the Ohio, and the Mississippi Rivers build up barriers in the river bed which impede their discharge.

They do this by digging out material, previously derived from caving banks, which has been deposited in deep pools. They pile up this material by deposits, where the velocity is lessened by the greater width, at localities where the curvature is reversed, or in the excessive widths in some of the long, straight reaches.

The main current, by cutting across the sharp points at the bends, takes a more direct course in floods than that followed in the low-water stage, and the distribution of surface slope which drives the water onward is much changed between low-water and high-water conditions. During low water, the slope in the long, deep reaches around the concave bends is so small as to be at times almost inappreciable, and the fall is concentrated almost wholly over the bars between these pools.

\* See Report by a Special Board of Engineers on the Survey of Mississippi River from St. Louis to its mouth, with a view to obtaining a channel 14 ft. deep, etc., Govt. Printing Office, 1909.

This 532-page report is literally crowded with valuable information and, together with the 296-page *Résumé of Mississippi River Improvements, 1st and 2d Districts, 1832-1902* by Major Eveleth Winslow, published in 1920, presents the best collection of data since the Humphreys and Abbot report that the writer has been able to find.

Professor Johnson made the surprising statement\* that the mean velocity of the water in great floods at some of these reversals of curvature, is only half the velocity then found in the deep pools at the bends, and stated that this reduction of velocity is the cause of the dropping of the sand and gravel which forms the bars at these localities. One naturally pictures the deep pool as having the smaller velocity, and this may be true at low stages. The pool, however, is deep only at its outer concave cutting-edge; the opposite edge is shallow; the straight reach at the cross-over is broader and more uniform. Professor Johnson pictured the whole river as a series of alternate pools and shallows, with first a reach of swift motion producing erosion and then a reach of slow motion with deposition.

He cited an example of how the river obstructs its own flow by the barrier built up during a flood, in comparing heights before and after a flood, at Columbus, Ky., about 20 miles below Cairo, with the same number of cubic feet per second flowing, and found, shortly after the peak of the flood had passed, that the river stood 2.15 ft. higher on the falling than on the rising stage, and that after the water had subsided farther, to near the normal low-water stage, the surface elevation was then 5 ft. higher than for the same quantity discharging prior to the flood, due to the deposit of gravel or sand dug from the curved pool by the flood and deposited in the slower velocity at the greater width of the cross-over bar.

The Humphreys and Abbot report, on Plates 14, 15, 16, and 17, presents abundant proof of similar facts.

As the result of his personal experience along the river and his later studies, Professor Johnson presented the following interesting conclusion:

"If this river flowed between straight parallel banks, such as Captain Eads has constructed at the mouth of the river, there could then be no such thing as this discontinuous transportation of sediment, and hence no alternate scour and fill. The concentration of volume would be beneficial, and would ultimately lower the river bed."

Judge R. S. Taylor, long a member of the Mississippi River Commission, had said that if all the caving banks were revetted, all the bars would be starved out; and that substantially all the bar-building sand or gravel is of local origin.

Professor Engels discusses this matter at much length in his treatise on river training and Mr. Francis J. E. Spring, in his book on Indian Rivers, presents sundry diagrams illustrating this succession of pools and shallows, and the concentration of fall at the cross-over bars.

By having a model of a section of river set up in the proposed laboratory, experiments would soon point the way to planning just how and where observations could be made most advantageously during the limited period while a flood is in progress, and could thus hasten the finding of useful facts in the river.

Captain Eads evidently was strong and clear in his belief that the way to improve navigation in the Mississippi between Cairo and Vicksburg was by narrowing the channel at these crossing-bars, so that the deposits as described

\* *Journal, Eng. Soc.*, July, 1886, p. 173, *et seq.*

previously would not take place. Efforts to carry out his ideas seem to have ceased with the costly experiments at Plum Point. The speaker believes it would be wise to revise Captain Eads' designs and make further trial, first in the laboratory, and, later, in the river.

*Flood Relief Channels vs. Navigation Channels.*—The navigation channel is chiefly a low-water problem. The flood relief channel is chiefly a high-water problem; and education for improving the two comes from different schools.

From reviewing much that has been written by European and American engineers, it seems plain that the attention of those who have attended Navigation Congresses, and those who have written on river training advocating a gently curving course instead of one that is straight, has been chiefly focused on the problems of navigation and of shaping channels so that deep water would run parallel to the concave bank at a uniform distance therefrom, and so that sand-bars and shoals would remain in the same place for a season. The pilot might then know where to expect them, and could hold his course with safety at some definite distance from the concave bank and have his mind at ease until he approached a reversal of curvature with its inevitable crossing-bar.

The Government engineer charged with river improvement often finds it far more economical to have his dredging operations for a 20-mile reach mainly concentrated within the fraction of a mile within the width of the crossing-bar, while Nature maintains a convenient depth, mile after mile, along the concave bank.

These conditions have led to a general commendation of the superiority of curved channels, to a general conclusion that Nature preferred a gently curving channel, and that it was "fighting Nature" to attempt to train a river in the straight and narrow way.

Those trained in the school for improving navigation seem to have generalized too broadly in their writings, and to have overlooked the very different requirements in training a river for flood relief.

When one focuses attention on flood relief, very different conclusions are reached, and on American rivers, flood relief and reclamation are just now a hundred-fold more important than navigation.

When one is designing a channel to carry the maximum quantity of water away quickly, he makes it straight and gives it all the slope or hydraulic gradient obtainable; moreover, it seems to be proved that, other things being equal, a straight channel will attack its banks less severely.

The problem of relief from flood may be worked out in two very different ways:

- (a) That of restraining the flow, as by the detention dams and reservoirs of the Miami system; or
- (b) By planning a channel that will take this water away as fast as it comes, or with all possible rapidity.

To make a long reach of river serve as a detention reservoir by maintaining it in a crooked course may have its beneficial uses, but is far from always

being the best plan; and a brief study shows that holding back the floods along the lower reaches of the Missouri, Ohio, or Mississippi by any system of separate reservoirs, is utterly hopeless.

Neither the textbooks nor the technical publications appear to recognize this difference between navigation and flood relief problems as clearly as desirable, and the speaker fears that the roots of the original deep-seated navigation motive sometimes obstruct the progress of the more recent flood-relief motive.

As to Nature's preference for a curving course, one must look farther and note that Nature's purpose primarily appears to be that of a slow, million-year process of leveling the mountains by erosion, transporting this eroded material by torrents and rivers, and depositing this far down the valley in those broad deltas and bottom-lands which are the farmer's best heritage.

It has been strongly maintained by many that, along the Mississippi and the Missouri, it was a mistake to interrupt this process of Nature and prevent the mud-laden flood waters from spreading across the delta over the lower lands farther from the river margin, and filling them to a higher grade; but these authors have not, as far as known, presented any figures as to the length of time it would take to fill these back lands with sediment at the present rate. The present condition of the low back lands shows that the best that the river has been able to do in 20 000 years or more since the latest glacial epoch, and computation with the best data doubtless would show that the completion of the job would require a period far greater than that which has elapsed since the dawn of history.

The proposed hydraulic laboratory will help greatly in studying the possibilities of training a river in a straight course, so that it will dig its channel deeper and carry its flood water and its burden of sediment promptly to the sea with the least possible damage to near-by farms or city plats; and it is possible that it will help to show how to lower the general flood-plain so that these back lands of the Mississippi and the Missouri can be easily drained, and that, for much of the way, levees will finally become no more necessary than the works of the ancient mound builder.

*Straight vs. Crooked Rivers.*—One of the unfortunate hasty generalizations derived from the predominance of the navigation idea, is that the curved is always better than the straight channel. Experiments could be set up in this laboratory for finding what, if any, are the objections and limitations to the use of a straight, deep, narrow channel for taking away with all practicable dispatch the mud or gravel-laden waters of a flood, and how far one can safely go in cutting out the bends in a crooked river.

The speaker has found most excellent reasons for believing that the Colorado River below Yuma, Ariz., which not only serves but threatens the Imperial Valley of California and the broad areas of cotton plantations south of the International border in Mexico, can be made most secure by confining it in the straightest practicable channel from Yuma to the Gulf of California and having a net width of less than 1 000 ft. (perhaps of only 600 ft.), with dikes on each side of the river protected on their outer face by heavy continu-

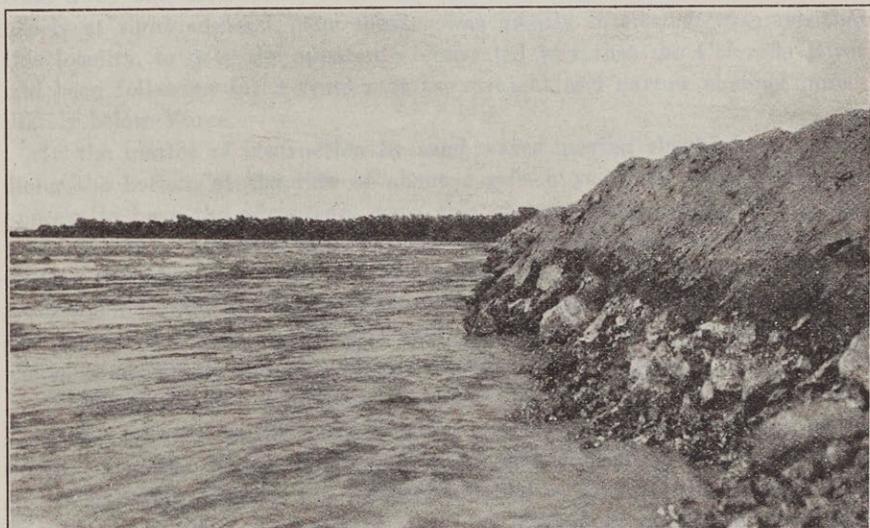


FIG. 32.—THE FLOOD THAT RUPTURED THE LEVEE BELOW YUMA ON JULY 1, 1921,  
PHOTOGRAPHED AT 5 P. M., JUNE 30, 1921.

The photograph shows the lower part of the tower on July 1, 1918. The tower is a tall, cylindrical structure with a flat top. It is surrounded by a low wall and a paved area. In the background, there are some trees and a building. The sky is clear and blue.

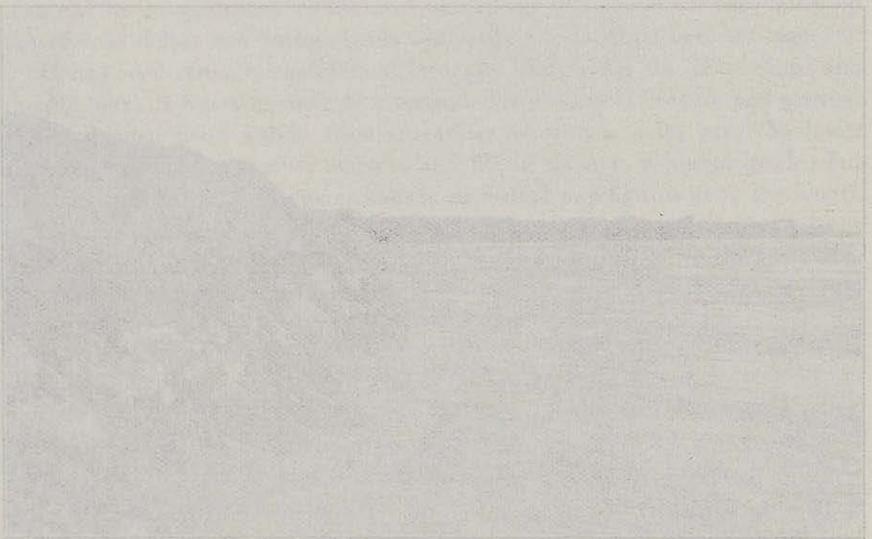


FIG. 32.—The tower during the lower part of the tower on July 1, 1918.

The photograph shows the lower part of the tower on July 1, 1918. The tower is a tall, cylindrical structure with a flat top. It is surrounded by a low wall and a paved area. In the background, there are some trees and a building. The sky is clear and blue.

ous rip-rap, possibly with the addition of groynes, say, 100 ft. long and 500 ft. apart, inclined down stream at  $30^\circ$ , with ends rounded off on 150-ft. radius and the outside rip-rapped, with a concentration of stones at the end and a big pile handy for repairs. A railroad along the top of the dike, fed from a quarry with broad working face and an ample reserve of stone, with steam shovels, cars, and locomotives should be always in readiness for rushing train-loads of stone to a threatened locality.

The narrowness and straightness of this channel would be among its chief elements of permanence and safety; for the speaker has been told by the engineers on the ground that they find that a flood does not "buck the dike" with nearly so dangerous an impact when flowing parallel as when it can first bend away and later come back and attack, with full force and momentum nearly at right angles. The speaker was greatly interested, when visiting this locality, to note the apparently contented way that the Colorado River had been following for 8 years past the straight and narrow channel immediately below Yuma.

In the matter of obstruction by sand waves moving slowly down stream along the bottom at the rate of about a mile a year, the straight channel appears to have the advantage, when this obstruction is compared with the crossing-bars in a curving channel at points of reversal, because the sand wave seldom extends more than half way across the river, commonly projecting from one side, and leaving the other free, while the cross-over bar extends all the way across. The sand wave is worthy of much closer study as to motion, shape, composition, and the contact velocity of the water.

*Whirlpool Erosion on a Convex Shore.*—One of the most instructive facts that has ever come to the speaker's attention relating to the method by which floods sometimes double the force of their attack on the convex shore, in a sort of hydraulic cyclone, was recently supplied by Porter J. Preston, M. Am. Soc. C. E., Resident Engineer of the U. S. Reclamation Service, at Yuma, regarding the crevasse in the dike, which occurred July 1, 1921, above Gadsen, on the east side of the river about 17 miles down stream from Yuma, at a bend in the levee. (See Figs. 32 and 33.)

For 10 days previously the river had been in high flood which gradually increased to 186 000 sec-ft., carried in a channel about 500 ft. wide. Such figures mean little to one who has not observed a flood of 100 000 sec-ft. or more in a narrow river. This is almost half as much as is carried by the St. Lawrence.

As shown in Fig. 34, the flow approached in two converging channels from around a bar or submerged island, the westerly channel being the more powerful. Gradually the easterly channel became weaker while the westerly increased, and although the water was rising and the discharge evidently increasing, the channel did not dig for itself a greater width. Finally, the effects of erosion began to show, and 242 carloads of stone were dumped from the railroad track along the levee at the threatened point, but in spite of this effort to hold the bank it failed, and a section 200 ft. long was undermined

and settled where half an hour before it seemed to be all right. Two hours later the breach was more than 1 000 ft. wide.

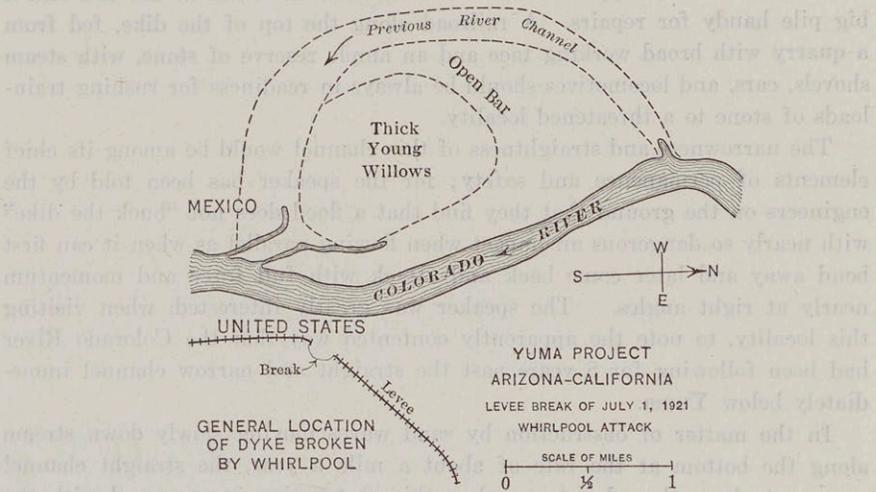


FIG. 33.

Now comes the story of special interest. For two days before the failure it had been noted that the surface of the water at the gauging station, some distance up stream, rose and fell about 1.8 ft. at frequent intervals, and along the converging channel it was noted that the current carried violent whirlpools which continued rotating down through the narrow channel, so that the advan-

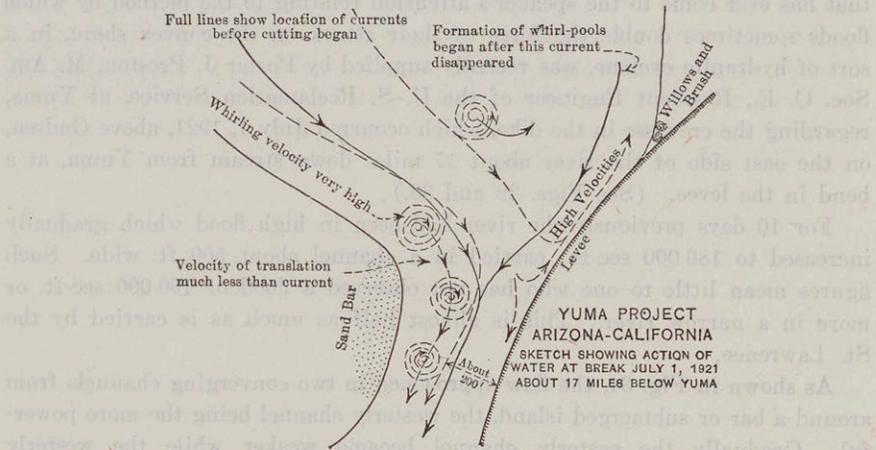


FIG. 34.

tage of the full sectional area was not had, because the off side of the current was traveling up stream or with small onward velocity, while the side of the whirlpool next the river bank carrying the levee tore past it with greatly increased velocity. These whirlpools passed at intervals of 4 to 6 min., and it

was while these were passing the narrows that the rise of the river gauge occurred, showing the effect of this obstruction.

The water level in the middle of the whirlpool seemed to be about 3 ft. lower than at the circumstance. The whirlpool rotated clockwise and thus cut hardest against the levee. In the general rush of efforts to save property, there was no opportunity for precise measurements of velocity or relative height, or to make soundings in the river. At the gauging station the depth meanwhile had scoured to 67 ft. where the channel was 570 ft. wide. That the water near the angle in the levee was being cut deeply was shown by trees 30 or 40 ft. tall drooping vertically as the river bank was cut beneath them.

It seems possible that the capricious development of some sort of a traveling whirl, somewhat like this, although less obvious, may have been the cause of the caving banks and the threatened crevasses at Stanton and Tunica, by giving an abnormally high concentration of current against the deep shore.

In the laboratory it would be possible to create and study such motions and probably learn how to prevent them. A feature of special interest is the possibility of their attack on a convex shore; another interesting fact is that a straight channel of uniform width presents less chance for their formation.

#### STRAIGHTENING THE RIO GRANDE

Another important case of straight *versus* crooked rivers is presented by the Rio Grande along a part of the International Boundary some distance eastward from El Paso, Tex. The Director of the U. S. Reclamation Service has recently submitted a report recommending that this be laid out and maintained on a straight course, and, although this defies tradition, the speaker is strongly inclined to believe it is the true solution, although he has not studied the problem on the ground. One of the engineers in charge of this work has stated that the saving in upkeep by cutting out one of the big bends in the river at this point would more than equal the cost of this proposed laboratory.

There has been trouble recently near El Paso from a cut-off; nevertheless, the speaker was told that the straightening of the river promises well.

#### STRAIGHTENING THE RED AND ATCHAFALAYA RIVERS

As proving that one must not generalize too fast and too far that cutting off bends and straightening a river leads always to trouble, the speaker is told that along the Red and Atchafalaya Rivers, below the channel which partly connects them to the Mississippi 200 miles up stream from New Orleans, evidence appears to be accumulating since the removal of obstructing "rafts," that even on a river of that large volume, flowing through much the same kind of alluvium that forms the bed and banks of the Mississippi, the cutting out of big loops has resulted in improvement.

On the Red River the speaker is informed that several cut-offs have been made, mostly near Shreveport, La., and that the bed has lowered 25 or 30 ft. since the raft was taken out, also that both low water and high water elevations have been lowered 8 or 10 ft.

The river has been shortened from 508 to 450 miles since the surveys in 1886-90. Where the change of length and location has been the least, the depths are said to be the least.

The speaker has been told that here for many miles the Atchafalaya flows in a deeper, narrower, and straighter course than 40 years ago, and at a flood height so much lower for the same number of cubic feet per second, due to the more direct discharge, that the annual flooding of the land along its borders is prevented with greater certainty by this lowering of the flood-plain than it could be by dikes or levees.

Can any one yet be absolutely certain that one of the most economical and certain ways to protect the lower 300 miles of the Mississippi from flood would not be by removing the sill that the engineers have built across the Atchafalaya outlet, and letting Nature take its course, thus providing the flood waters of the Mississippi a short cut of about half this present distance of 300 miles to the Gulf? Probably this would be opposed violently by residents along the Atchafalaya, in the expectation that it would increase the flood dangers along their own river, and the speaker is far from recommending it.

#### TROUBLES CAUSED BY CUT-OFFS

As to preventing cut-offs, no one can doubt that cut-offs across bends have in most cases caused a lot of trouble, and that the shortened course, greater slope, and higher velocity has started new caving of banks, with all attendant disasters, and has upset the regimen for perhaps 50 miles along the river.

Proofs of such trouble have been all too abundant in the 43 years since the Mississippi River Commission was organized, and it would seem that the Commissioners and the engineers have not wavered from the original thesis, that cut-offs should be prevented. Nevertheless, it is not impossible that there are places where systematic cut-offs could be beneficial in lowering the flood-plain. Nearly all troubles hark back to the caving bank and to its feeding the current with sand, silt, and snags, to be soon deposited on the bars, and which the engineers then have a lot of trouble in digging out. Each cut-off in this crooked river by shortening the distance increases the slope which increases the velocity and gives the current new twists against the bank, and increased cutting and caving of banks ensues. The recorded discussions of Captain Eads, Professor Haupt, and others indicate that on many of these difficult problems, perhaps, as in the old story, conclusions have sometimes been reached before finding opportunity to study both sides and all the edges of the shield.

Most engineers who have studied these matters will admit, with Capt. Eads, that, with a straight river and with means of holding it straight, it would give less trouble than at present.

Is it not too soon to admit that means of holding it, that will be cheaper than the continuous revetment, "can never be found?"

As, in the course of time, as the river naturally changes its meander back and forth, it takes many positions, why might it not be possible in a 20-year program to coax it, by some new form of spur, gradually to take a straighter alignment? And why not be content to wait for 20 years more as we have waited for 20 years past, for the great revival of navigation, and meanwhile

help the river into a shorter course that would cause it to dig itself into a deeper bed, that would carry the flood without overflowing the banks.

In other words, with the aid of the laboratory and of the model channel let us look again into some of these questions of straight *versus* crooked rivers, recognizing that some new, cheap, effective form of spur-dike must be devised of sufficient endurance and strength to withstand these deep strong currents.

The failure of the proposed laboratory to point the way to success, would be far less costly than either of several experiments in the field which have been unsuccessful, and there would still be much useful work for it in other fields.

Foote's extensive plan for a National Hydraulic Laboratory, which is published in the report of the Mississippi River Commission, is the main object of this discussion. Mr. Foote has shown clearly the pressing need for such an agency of investigation and that there is no other National agency likely to serve this purpose at a moderate cost. He is not a responsible name in the field of hydraulics, but his report is one of the most valuable for many years, but for want of such a laboratory has been consigned to constant neglect. The writer has been engaged for the purpose of making investigations in river hydraulics. About ten years ago when the writer was a professor in the University of Minnesota, he recommended to the University authorities that the river at the lower end of the near Fort Snelling on the Mississippi River be deepened and an extensive hydraulic laboratory established as an appendage of the water-power development. It is certain that it would have benefited the University and that the postponement of this question until there is an urgent necessity to get a share of the power, or to establish a comprehensive hydraulic laboratory, was a mistake. The writer has been at Hannibal, Mo., on the west bank of the Mississippi River, where he saw the river in flood many times. On several occasions the low bottom on the opposite side of the river was flooded and many small levees broke in the lower part. At one time there was a crevasse 300 or 400 ft. wide. It is remembered that one of his neighbors lost all his crop consisting of several thousand bushels of the wheat by that overflow. This was more than 100 miles north of St. Louis, Mo., far beyond any possible effect from the Missouri River, which empties into the Mississippi below Hannibal, near Alton, Ill. Damages on the upper river are insignificant in comparison with the great losses below. The writer is also familiar with the Missouri from its source to its mouth. The river basin at the junction of these rivers near Helena, Mont. These rivers and the main river are comparatively clear in their upper reaches and are torrential in places. Their main burden there is composed of gravel and heavy stones, which at times can be seen and heard rolling down near the bottom. There is comparatively little sand and fine silt. However, after travelling over Great Falls and getting out into the plain of Montana and thence the Missouri becomes truly the Big Muddy. This is due to cutting of the banks and the forlorn heads that are eroded rapidly.

DISCUSSION ON THE RIVER AND HARBOR PROBLEMS  
OF THE LOWER MISSISSIPPI

BY MESSRS. B. F. GROAT, HARDY CROSS, L. W. WALLACE, L. K. SHERMAN,  
MORRIS KNOWLES, GARDNER S. WILLIAMS, A. W. NEWTON, JOHN MILLIS,  
and C. E. GRUNSKY.

B. F. GROAT,\* M. AM. Soc. C. E. (by letter).†—Little can be added to Mr. Freeman's exhaustive plea for a National hydraulic laboratory, except to endorse it *in toto*; and that is the main object of this discussion. Mr. Freeman has shown clearly the pressing need for such an agency of investigation, and that there is no other National agency likely to serve this purpose at a moderate cost, or within a reasonable time, if at all. The writer not only has been aware of the urgent needs in this respect for many years but, for want of such a resource, has been compelled to construct outdoor laboratories, on several occasions, for the purpose of making investigations in river hydraulics.

About 15 years ago, when the writer was a professor in the University of Minnesota, he recommended to the University authorities that the power at the lower dam site near Fort Snelling, on the Mississippi River, be developed and an extensive hydraulic laboratory established as an appendage of the water-power development. It is certain that it would have benefited the University, and that the postponement of this question until there is at present not much opportunity to get a share of the power, or to establish a comprehensive hydraulic laboratory, was a mistake.

The writer was born at Hannibal, Mo., on the west bank of the Mississippi River, where, as a boy, he saw the river in flood many times. On several occasions, the Sny Bottoms, on the opposite side of the river, were flooded and many crops lost by breaks in the levee. At one time, there was a crevasse 300 or 400 ft. wide. It is remembered that one of his neighbors lost all his crop, consisting of several thousand bushels of fine wheat, by that overflow. This was more than 100 miles north of St. Louis, Mo., far beyond any possible effect from the Missouri River, which empties into the Mississippi below Hannibal, near Alton, Ill. Damages on the upper river are insignificant in comparison with the vast havoc below.

The writer is also familiar with the Missouri from its source to its mouth. The river begins at the junction of three rivers near Helena, Mont. These rivers and the main river are comparatively clear in their upper reaches, and are torrential in places. Their main burden there is composed of gravel and heavy stones, which, at times, can be seen and heard rolling along near the bottom. There is comparatively little mud and fine silt. However, after tumbling over Great Falls, and getting out into the plains of Montana and Dakota, the Missouri becomes truly the Big Muddy. This is due to caving of the banks, and the fertile soils of the margin lands that are eroded rapidly.

\* Cons. Engr., Philadelphia, Pa.

† Received by the Secretary, April 17, 1923.

All such eroded material is destined ultimately to reach the sea; it is lost for purposes of agriculture. In the writer's opinion, all this erosion can be stopped. One of the best ways to test any proposed method for such a purpose is with a model, under carefully planned laboratory conditions.

To give some evidence that laboratory tests on models can lead to accurate conclusions as to what will happen on full-sized rivers, the writer will relate briefly some results from one of his outdoor hydraulic laboratories. One of the problems was to construct, within 60 days, a temporary dam across the South Sault Channel of the St. Lawrence River. It was to be a weir-dam, at times to spill water over the crest. The channel was more than 500 ft. wide, nearly 20 ft. deep in the middle, and from 8 to 10 ft. deep near the sides. The current was strong and rapid, having a maximum velocity of about 12 to 15 ft. per sec. The plan proposed was to drop large stones in a line across the channel from the sides of scows held in place by a cable and anchor above, continuing the process until the dam was raised to the proper elevation.

Although this was a difficult and unusual engineering work, thought by many not to promise success, the problem was solved satisfactorily with a model of the channel in the vicinity of the dam site. One of the main questions to be answered by the model, for example, was the correct minimum size of stones that would lie in place after being dropped into this swift water. The model was built on a scale of 1 to 100. It was found that pebbles  $\frac{1}{2}$  to  $\frac{3}{4}$  in. in diameter would lie in place in line in the model when proper model conditions were established. From this, it was concluded that actual stones, 4 to 6 ft. in diameter, would lie in place in the river channel, because, for a scale of 1 to 100,  $\frac{1}{2}$  in. represents 1 ft., approximately. Accordingly, stones of this and larger sizes were purchased, and the dam was constructed as planned.

To show that the model indicated correctly, it may be mentioned that the superintendent of construction, being impatient to start work and having no large stone on hand, constructed about 50 ft. of the north end of the dam with smaller stones—most of them less than 2 ft. in diameter—taken from a neighboring field. During a subsequent rise of the river, after the dam was nearly complete, this section of under-sized stones was washed out. The success of the method in this case depended on the fact that the river bed was of firm hardpan, not likely to be cut so as to undermine the large stones.

In addition to the problem just described, the larger one of relieving ice conditions was solved, so that a power plant which was practically shut down in winter is now capable of developing 50 000 or 60 000 h. p. The use of the laboratory model assisted in ascertaining the proper dimensions of the works, so as to give the writer's invention sufficient capacity to carry the ice away so rapidly that no opportunity was afforded for a jam to form, obstruct the waterway, and cut off the supply of water for the power plant.

One use for a laboratory, that should be strongly emphasized, is the publication of the physical laws by which correct interpretations may be placed on the indications of models, so as to obtain correct quantitative conclusions relative to the action of the full-sized river. Many such laws are now known

to a limited number of engineers, and it will be an important function of the organization of the National hydraulic laboratory to prove these laws and publish the information in such manner as to establish, or introduce broadcast, this valuable method of solving engineering problems. It is self-evident that the action of a model must be far more conclusive than a mere engineering drawing, the latter being more the product of the artist than the result of an engineering investigation. It is difficult to admit that there is any other way of attacking effectively some of the problems of flowing water than by the use of a model. Only certain ideal cases of flow can be handled mathematically; actual cases have been solved only by experiments on models, and it is remarkable how few engineers know the laws that have been established in relation to models. In many, if not most, of the tests on models, the experimenter has been ignorant of the laws and has proceeded with his tests in his own way, frequently to find that he must repeat them with correct proportions before he can obtain exact results. One of the most valuable functions of the proposed laboratory will be to stop all this misdirected effort, and remove the necessity for each engineer to study his model before he can study his problem by means of his model.

There are many problems of the sea, some of them becoming urgent, which await solution in the laboratory. A serious condition exists near Barnegat City, N. J., for example, on the south cape of Barnegat Inlet, where the famous lighthouse is now threatened with destruction by the encroaching sea. A house has been washed away, and the sea is now at the very base of the light. The explanation of this may be inferred from the following quotation:\* "Barnegat Inlet has been moving slowly southward for many years." Besides this it is stated in the "Coast Pilot" that the entrance channel is unstable and that the buoys cannot always be depended on to mark the best water. Observations show that large quantities of material may be cut away from many miles of beach along the New Jersey shore in a single night by a high spring tide with a heavy sea. Cuts of 3 or 4 ft. frequently take place within a few hours along the whole shore. The material may be shifted back gradually within the next few days, or nearly so, but there is no doubt that a slow progressive change is taking place along the entire coast in this vicinity, and that, before many years, the problem of protection will become so acute that it will require urgent attention. No doubt many of the attendant problems could be solved most profitably in such a laboratory as that proposed by Mr. Freeman. It may be even possible to develop feasible means for stopping such a progressive movement as that at Barnegat Inlet.

Looking at an ice jam, or the immense deposition of material at the mouth of the Mississippi, or the movement of the opening to a large bay like that of the inlet to Barnegat Bay, one is appalled by the magnitude of the problems, and is apt to conclude that a process, such as an ice jam, is so stupendous that nothing can stop it. The truth is that the process is gradual until the breaking strain is reached. The calamity can be prevented by setting another

\* "United States Coast Pilot", Atlantic Coast, 1916 edition, p. 55.

gradual process of counter effect in operation, that will relieve stress and strain as fast as it tends to pile up, so that no calamity can occur. If, for example, improvements which seem to be entirely feasible were made on the Missouri and Mississippi Rivers, the sedimentation could be reduced to such an extent that no further appreciable building up of the Mississippi Delta could take place. The results of such an improvement might be a succession of valuable water powers along the two rivers, the reclamation of swamp lands along the lower river, and the conservation of fertile soils on the upper rivers, especially on the Upper Missouri. If the whole scheme is planned with view to flood digestion, as against flood prevention—that is, a plan for flood handling so as to avoid undue sedimentation—the flood danger would also be eliminated. As such problems are among the greatest of all engineering and economic problems that will ever be raised, it is certain that the trifling cost of a National hydraulic laboratory, even if it should be several times the estimated cost of the one proposed, would be well justified as the foundation of an agency to study them.

Although there can be no doubt that the main object of the laboratory should be the study of the larger problems of hydraulics connected with the training of great rivers, it is equally certain that it should be amply equipped for the smaller studies in hydraulics. This laboratory should be the center of hydraulic learning, the National center, where the leading men in hydraulic science would naturally go to solve their problems and publish their results. The custodian, or director, of the laboratory should be free to exercise independent thought and action, and not be so dependent on other departments that he would feel in the least trammelled, when making his reports, for fear that he might come into conflict with fixed opinions and set customs of a nature obnoxious to scientific progress. No problem can be solved so as to stay completely solved for all time. Sooner or later, knowledge will advance to a point where the inaccuracy, or insufficiency, of the former solution will become apparent. Science has its fashions. Hence, it will not be at all surprising if new methods for improving large rivers like the Mississippi should develop at any time; why not soon, in a National hydraulic laboratory, such as that now proposed?

One feature of such a proposed laboratory, which deserves special attention from the very beginning, refers to inventions. It seems to be altogether too prevalent for large corporations, powerful employers, foundations of one sort or another, and some of the professions, to take advantage of inventors. When a real inventor is at work, his last thought is for himself. He concentrates his time and scientific thought on study and investigation concerning his invention. While he is thus engaged, possibly on very important work, his employer, or some attorney of an employer, may be keeping himself busy to see how the patentee, or inventor, can be divested of his rights, perhaps even before the invention is complete. Not only this, but it is becoming the fashion of corporations and even some professions to throw out propaganda of one sort or another which is of a prejudicial nature to invention and inventors. The

last profession to obstruct the progress of invention in this manner should be that of the engineer and engineering institutions. This whole matter should form part of the organization of the proposed laboratory so as to accord proper protection to the inventor during the progress of his work, and, on the completion of his invention, he should have his rights defined by proper authority. Every reasonable inducement should be held out to inventors to perfect their inventions.

Mr. Freeman wants to train rivers to carry their burdens of sediment to the sea with despatch, but the writer would train them not to pick up any sediment. Apparently, these are two conflicting principles, either one of which will accomplish certain results. It is right here where there is diversity of opinion and possibility that an efficient laboratory would come into play. In a majority of cases, it could settle, in a short time, questions relative to two or more possible methods of attacking problems. It might thus advance by months, or even by years, the time when actual work could begin on important National projects where there might be great diversity of opinion.

HARDY CROSS,\* M. AM. SOC. C. E. (by letter).†—Mr. Freeman once told the writer that he hoped to conduct a certain investigation in part payment of his debt to the great engineers who had gone before. His advocacy of a National hydraulic laboratory is surely such a service, both to the profession and to the nation. He has cogently summarized the arguments for such a laboratory, and little is left to be said by those who favor the movement which Senator Ransdell has had the clear vision to sponsor.

The writer has heard the following arguments stated by skeptics: The problems involved were said to be too intricate for laboratory investigation, and the conditions of the laboratory to differ too widely; undoubtedly the director of such experiments must be a man of clear vision, with a rare combination of theoretical foundation and practical perspective, for much laboratory work is worse than useless, because the theory is half-baked, some elements in the practical problem being omitted, and the proportions of others distorted. But nothing, perhaps, is so obviously impractical as the attempt to establish natural laws by field experiments on fluvial phenomena. Many of the fundamental data cannot be determined in the field; it is, for example, nearly impossible to study the average elevation of the stream bed at the flood stage, as the rise or fall at the gauge may be due to conditions at a single bar. Also, the application of the statistical method evidently limits the number of allowable variable factors.

Mr. Freeman has shown how to use the practical case as a check on conclusions and as a control for determining homologous proportions. Experiments made abroad show clearly the practical value of laboratory experiments on rivers.

As Mr. Freeman has stated, the first work of such a laboratory would probably be that of collecting the scattered data and opinions—chiefly the latter—and then the standardization of terms and the establishment of quanti-

\* Prof., Structural Eng., Univ. of Illinois, Urbana, Ill.

† Received by the Secretary, April 18, 1923.

tative units. At present, the average engineer cannot properly collect field data, for he has no definite terms to describe the phenomena or units by which to measure them. He can show a circle and mark it "eddy" or "big whirl", or can describe the sediment as "sand" or "fine sand" or "mud", but much more exact terms are needed. The classical argument between Eads and Abbot as to the sediment saturation of the Mississippi is an example of the effect of chaotic nomenclature in this field; and the situation has not greatly improved since their time.

The writer recently had the pleasure of discussing some of the problems of sedimentation with Professor A. C. Trowbridge, of the University of Iowa, who is making for the U. S. Geological Survey a study of sedimentation in the mouths of the Mississippi, and was impressed by the close connection of the fundamental problems with those of molecular physics. Mr. Freeman is right in claiming that this connection can best be made in a laboratory. Geologists and engineers especially have failed to correlate their data, and the establishment of a National laboratory would certainly facilitate such correlation.

Undoubtedly, the most immediate and tangible value of such a laboratory would be qualitative. Hypotheses would suggest themselves, and these would lead to a more intelligent collection of field data and a more rational study of those already collected. Out of all the welter of opinions and dogmas, the writer has been able to find scarcely one which has not been debated by eminent authorities. Evidence of the discouraging uncertainty as to fundamentals is found in the recurring controversy as to the effect of a spillway near New Orleans.

This laboratory will be of value not only to the States of the lower valley, but to almost every State, for each has its own flood problem, and it is probable that the aggregate of capital threatened by floods is greater outside the States of the lower valley. The cut-off problem is important in Illinois and in other States where river improvements are being made by dredging. Engineers owe to the public the duty of advising as to the effect, on flood levels down stream, of this dumping of flood waters, but data from which to compute these effects are lacking.

It seems to be very desirable that the river flume should permit the inclusion of the effects of flood-plain flow and storage, and of tributaries. The writer has given much thought to such a layout, and has arrived at the tentative decision that the best model is a channel formed in a box filled with the material to be investigated or an homologous substitute, the box being approximately square and the channel winding around near the periphery and discharging near the point of origin. A flood-plain could then be formed on the inner side of the channel, and a tributary, fed from an auxiliary weir supplying the main stream, could be made to join the main channel along this inner bank. This would provide great flexibility for the experiments. Such meanders as the Greenville Bends could be reproduced, chutes, islands, and diversions could be modeled, delta flow studied, cut-offs conveniently effected, and the shifting of the thalweg with the stage investigated on a large scale. A

return channel would also make it possible to duplicate or vary slightly at two or more points, the reach to be studied, however crooked it might be, and thus, during a given run, check or control observations could be secured. This type also presents advantages of compactness and probably of economy of time for the observers. The central area could be made readily accessible.

Such a design is also well adapted to studies of rates of travel of the flood wave and the effect thereon of curve radius and of total curvature. For the study of estuary problems, it also seems to be well suited. Slope could be secured by grading the floor and adjusting the depth of fill, and the regulation of the height of the weirs at entrance and discharge would cause the stream finally to grade its own bed. Any river experiment almost necessarily starts with the stream in approximately stable regimen for a given discharge.

The writer's idea is that the weir flume should be independent of, but under the same roof with, the river flume, for he believes that the latter would be in continuous use when once established. This need not preclude the centralization of pumping and measuring apparatus. The writer's plan, therefore, differs from that of the author in separating the weir flume and in making the river flume square instead of rectangular. By placing auxiliary stilling basins at the corners, three straight runs could be secured, affording a check, or these could have variations in slope or hydraulic radius. This would provide a shorter straight run, but a much longer sinuous channel for the same area of tank. Most of this tank would consist merely of an impermeable floor resting directly on the ground, the pits for tanks, measuring apparatus, and pumps being entirely at one end. In order to reduce the first cost to a minimum, the writer would not provide a tilting flume, as it is not essential, although it is evidently desirable and could be added later.

Mr. Freeman's remarks on the study of bridges are of great interest. The design of river crossings, as distinguished from the structural design of bridges, has received little attention in American literature. Many low-level bridges are being built too long, if one only knew how to make them shorter; and a river laboratory should help to remove that absurd "if". Engineers need to know the limiting depths of scour, more about scour around piers, and methods of pier protection, the pressure due to permeable rafts of drift—sometimes of enormous size in Western rivers—lodging on piers, the back-water from river crossings, and more relating to the eddies that undercut embankments. The maximum velocity for a given flow through a bridge opening cannot be estimated accurately until the constriction due to eddies is studied. An excellent example of this is cited by the author. The size and velocity of translation and rotation of these eddies, their scouring effect, and the whole history of eddies and boils should be investigated.

Studies of the change of thalweg between low and high water are especially needed, as well as the effect of bridge openings in "drawing" the thalweg. Many supposedly square crossings are skewed to the flood current. The Indian engineers, as Mr. Freeman points out, have done some excellent work along these lines, but the results are not usually available to engineers in America,

as only a few libraries are supplied with the technical publications of the Government of India.\*

The prospective value of this laboratory to irrigation and drainage, in bridge and railway engineering, in power development, and in flood protection, justifies cordial support for its establishment.

L. W. WALLACE,† Esq. (by letter).‡.—The writer was amazed when he heard Mr. Freeman, in the course of an address before the District of Columbia Section of the Society, some months ago, make a statement to the effect that the only scientific laws available relating to river flow and flood control were those developed on a section of a small river in France about 100 years ago, supplemented by the work of Capt. Humphreys and Lieut. Abbot on the Mississippi more than 70 years ago. Considering the great havoc obtaining at that time along the Mississippi and other rivers of the United States from flood waters, this statement made such an impression on the writer that he gave it careful consideration for some days.

In the meantime, having made some investigation as to what was being done, he learned that several hundreds of millions of dollars had been spent in an endeavor to control the Mississippi and hundreds of millions more would be required before an adequate protection had been assured. Furthermore, it developed that there was no unanimity of opinion among the best informed engineers as to the wisdom of the means being used. It also developed that conditions and circumstances like those obtaining along the Mississippi existed along other rivers of the United States.

Moreover, the writer became convinced that one of the most pressing problems confronting the American people was that of a scientific study of river flow and flood control. These studies are important, not only from scientific, but from economic and social points of view. If one asks why this is true, the question is readily answered.

In the first place, the Federal Government and the several States are spending approximately \$116 000 000 annually in such work. Yet it is stated that the scientific basis for such expenditures is wholly inadequate.

Secondly, almost every spring, large acreages are flooded, resulting in great loss of property and of life, and much personal hardship.

Thirdly, the United States, for some years, has suffered from inadequate transportation facilities and from high charges for the transport of goods. It is of paramount importance, from both social and economic standpoints, to develop waterways for transportation purposes. It is entirely probable that such a laboratory as that proposed by Mr. Freeman would contribute materially to such a desirable end.

In the light of the foregoing considerations, Senator Ransdell was approached because of his known interest in waterways in general and the Mississippi River in particular. It was found that he had studied the problem

\* This work is reviewed in part by William Lumisden Strange in his "Notes on Irrigation, Roads and Buildings, and on the Water Supply of Towns" (Lond.), George Routledge & Sons, Ltd., 1920.

† Executive Secy., Federated American Engineering Societies, Washington, D. C.

‡ Received by the Secretary, April 18, 1923.

rather actively for 30 years. When he was informed of Mr. Freeman's ideas regarding the need for a National hydraulic laboratory, he was pleased and sought an interview with him. This resulted in a Joint Resolution being introduced in the Senate providing for such a laboratory. A Sub-Committee of the Senate, with Senator Ransdell as Chairman, was authorized to handle the bill. The Committee held two hearings before which a number of eminent engineers testified. Mr. Freeman presented an exhaustive and an able argument in favor of such a laboratory. The Sub-Committee and the Committee on Commerce of the United States Senate, in turn, reported the bill favorably. Therefore, it will automatically find a place on the calendar when the Senate convenes in December, 1923.

It is not incumbent on the writer to set forth arguments for this bill, nor to list the projects that may be undertaken by the laboratory when it is established. These matters have been ably covered in the hearings and in the several utterances of Mr. Freeman. The writer desires to state that he believes this is a much needed piece of legislation, in the interest of science and the economic and social welfare of the nation. Furthermore, the Federated American Engineering Societies has supported, and will continue to support actively, the movement for the establishment of a National hydraulic laboratory. It is hoped that the engineers of the United States will recognize the need for and utility of such a laboratory and will use their influence with their respective Congressmen and Senators to the end that it may soon become a reality.

To Senator Ransdell and Mr. Freeman much credit is due for their vision and active leadership in bringing this matter forward, and for the favorable position it is in. It is a project deserving the active support of the American people and particularly of engineers who can evaluate its potentialities.

L. K. SHERMAN,\* M. A. M. Soc. C. E. (by letter).†—All engineers who have had any experience with land reclamation, flood control, or shore protection will endorse Mr. Freeman's plea for a National hydraulic laboratory. National legislators will realize the importance and value of this work when they are convinced that such laboratory experiments are not merely of academic value to the Engineering Profession, but will be the means of saving hundreds of thousands of dollars to the people in the river valleys, as well as to the States and the Federal Government.

The problem of river regulation depends on the end in view. The procedure for aiding navigation is not necessarily the same as that for land reclamation and flood control. Successful practice in one locality has not proved successful elsewhere. A National hydraulic laboratory would show why. A laboratory observation may give a negative result, but the result is a constructive experiment. A negative result on a full-sized attempt in the field is a costly and dismal failure.

In connection with work on land drainage districts, the writer has studied the available data and theories for channel improvements, and has been impressed by two things: (a) The wide divergence of opinions among engi-

\* Pres., Randolph-Perkins Co., Chicago, Ill.

† Received by the Secretary, April 18, 1923.

neers on the subject; and (b) the meager data available on which opinions can be based.

The need for fundamental data was so obvious that, in lieu of anything better, the writer arranged a small adjustable flume and undertook a series of experiments to determine the hydraulic laws of the variation of the time of flood-wave movement with change of slope. These experiments were made in the fall of 1922, and were the subject of a paper entitled, "The Effect of Upper Channel Improvements on Down-Stream Flood Heights", presented by the writer before the Western Society of Engineers, on January 9, 1923.

Regardless of any specific value of these experiments (which were limited by the meager means and the short time available to a practicing engineer), they did demonstrate the great need for and importance of conducting such hydraulic experiments on a comprehensive scale.

Experiments relating to the time of travel of flood waves would increase the facilities of the U. S. Weather Bureau in its valuable work of forecasting river stages and flood peaks.

The writer would commend the constructive idea of Mr. Freeman, that a National hydraulic laboratory might demonstrate the feasibility of methods of river regulation other than by continuing to increase flood heights and raising the levees.

MORRIS KNOWLES,\* M. AM. Soc. C. E. (by letter).†—The proposal advanced by Mr. Freeman for the establishment of a National hydraulic laboratory should receive the earnest consideration of all engineers and be of particular interest to those engaged in hydraulic studies. In reference to floods and flood prevention, one cannot help being impressed by the discussion by H. M. Eakin, Esq., at that time Geologist in the U. S. Geological Survey, in which he mentions‡ the necessity of studying many different branches of science in attempting to solve the problems of stream control.

The school laboratories have done much, but they are too small. There is need of facilities, supported by larger endowment, and directed by men of extensive experience, who will be attracted to aid in solving these abstruse problems and learn the laws which control the behavior of streams under different conditions. As Mr. Freeman has well pointed out, some European Governments are far in advance in the establishment of large research laboratories under National jurisdiction; and it may well be considered whether this does not explain their much more complete use of water flowing in streams, and with this utilization a greater development in stream regulation, so that devastating torrents are applied to Man's useful work.

When one thinks of the relatively small sum of money required to establish and maintain such a laboratory, one wonders why there should be any opposition. Surely past experience with waterway improvement in the United States demands that Americans, as a people interested in scientific knowledge as a basis of all efforts, shall insist on acquiring all information possible before

\* Cons. Engr.; Pres., Morris Knowles, Inc., Pittsburgh, Pa.

† Received by the Secretary, April 19, 1923.

‡ *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), pp. 1235-36.

expending such vast sums of money. It is to be hoped that opposition is not based on a fear that the knowledge to be acquired may upset some pet theories, long held.

Even if it is granted that such a laboratory develops no new facts or methods, it certainly will cost only a small proportion of the vast National sums expended, in order to prove what is fallacious and what is good, and thus end the almost continuous discussion as to whether certain methods now being followed are right. It would be worth while, even for this purpose, if for no other. If experience in Europe signifies anything, it is that engineers have much to learn about the behavior of rivers, that the natural sciences have much to give, and that careful, accurate, scientific study is needed in order to determine the laws on which appropriations for important public works should be predicated.

The writer is glad to state that the people of the Pittsburgh region of the Ohio Valley, which is a part of the great Mississippi Basin, welcome investigation and the acquirement of knowledge. In this manner a suitable National policy may be developed, which will ultimately save monies by promoting wise expenditures. Members of the Society could perform no greater service than to make it apparent, to their Senators and Representatives in Congress, that engineers, as scientific men, believe that investigation and experiment, to develop the scientific laws governing stream flow, will result in an important contribution to the advancement of the art of river regulation and ultimately indicate the manner in which the public monies should be spent for control works.

GARDNER S. WILLIAMS,\* M. A. M. Soc. C. E. (by letter).†—The writer can add little to Mr. Freeman's very complete presentation. Most engineers agree that the great difficulty found in river hydraulics is that the channels cannot be straight. They perhaps are not so well agreed as to the reason.

In a long straight reach of symmetrical and uniform section, the velocities of the flowing water arrange themselves in a progression from slowest at the bottom and sides of the channel to swiftest at or near the surface at the center. Bernoulli's theorem teaches that in a moving fluid where velocity is least, pressure is greatest, and that pressure head and velocity head are interchangeable. Experiment has demonstrated the correctness of this proposition when applied to the different layers of water flowing in a pipe. It follows, therefore, that a particle of suspended matter in such a reach as that predicated, in order to travel from a higher to a lower level, must do so against an increasing pressure.

As has been learned from laboratory investigation that, whenever water passes around a bend, whether in a pipe or an open channel, there is a disturbance and re-arrangement of the velocities in the verticals of the flowing stream, and throughout a part of its cross-section the velocities in the lower half are accelerated and those in the upper half retarded, so that there is a nearly uniform velocity throughout each vertical and, consequently, uniform pressure

\* Cons. Engr., Ann Arbor, Mich.

† Received by the Secretary, April 19, 1923.

from top to bottom. The particle of suspended matter no longer has to overcome an increasing pressure as it descends, but finds its deposition made easy. Consequently, suspended matter is deposited throughout a part of the stream at every turn. A like phenomenon takes place as a stream passes into a contraction, and—what is more interesting and until comparatively recently unsuspected—a similar equalization of velocity in the vertical takes place after passing through an expansion.

Why does not the head of a rapid erode its bed? Some will answer that it does; but the rapids at Sault Ste. Marie and on the St. Lawrence River, although they flow over only a moderately hard clay, do not seem to have eroded their beds appreciably within historic times. In those channels, the velocities from top to bottom are nearly uniform in the swiftest parts, and the pressure required to lift material from the bottom is lacking. For the same reason, a bar tends to move up stream.

Here, then, are the fundamentals of normal scour and deposition. The straight-moving stream tends to take up and carry in suspension particles from its bed and banks, irrespective of the scour caused by eddies and oblique currents, because the pressure in the saturated material at its border is greater than in the layer of flowing water adjacent to it, and the pressure in that layer is greater than in the one next above it, so that the particles are lifted upward by the pressure beneath. Near the bounding surfaces the velocities and pressures change rapidly, but, approaching the top and center of the stream, the change from layer to layer is much less, so that, in such a stream, there is a continual contribution of suspended matter from the bed and banks to the swifter and more uniformly moving water in mid-stream. Moreover, as the mean velocity is increased, the change of pressure from layer to layer increases, and *vice versa*, so that more material is picked up by a swiftly flowing current, and more deposited from a slow one.

When, however, a curve, a contraction, or an expansion, is passed, all this is changed, and the stream deposits a part of its burden irrespective of a change of average velocity.

Thus far, the path is fairly clear, but it now becomes necessary to take account of local disturbances in the flowing stream, such as eddies, rapids, wind, and barometric effects, and character of border material.

These conditions rapidly take the investigator beyond the reach of simple theory or complex mathematical analysis, and require for the solution of the problem accurate and controlled experimentation. Such experimentation can be carried out only in an especially constructed laboratory, as only there can the influence of the various factors be controlled, studied separately, and their true effects established. No great progress can be expected, unless as the result of accident, by experimentation in the field without laboratory accompaniment, and, in view of the large interests involved, it seems strange that a laboratory for the study of river hydraulics was not established long ago.

A. W. NEWTON,\* M. Am. Soc. C. E. (by letter).†—From experience on the Missouri River, it is the writer's opinion that this method of river-current

\* Chf. Engr., C. B. & Q. R. R., Chicago, Ill.

† Received by the Secretary, April 20, 1923.

control has not yet been developed to its fullest extent, and that its possibilities are much greater than have yet been established. Experience will be helpful in determining the proper location of retards such as are constructed by Woods Brothers, and there is more to be kept in mind than the protection of lands that are being washed away, because, in a stream such as the Missouri, a shifting of current or change in direction of current can cause no little trouble elsewhere, and this is one of the problems that must be considered in work of this kind.

The writer believes it can be stated truthfully that the experiences on the Chicago, Burlington and Quincy Railroad, from an economic and effective standpoint, are far in excess of the most sanguine hopes. To be sure, the early stages of this work were experiments, but, as experience is gained, more effective work may be expected.

JOHN MILLIS,\* M. AM. SOC. C. E.—The realization of the basic ideas that are advanced in Mr. Freeman's paper would certainly be a greatly desired accomplishment. The speaker is sure that all practical engineers will concede this to be true.

Numerous advantages may be recalled that have followed from similar policies in other departments of the Federal Government, such as Forestry and Agriculture, by which some of the most important discoveries and advances in those activities have been developed by experimenting practically on a large scale.

The civil engineer is a man of science, as has been remarked previously, but in addition he must be pre-eminently a man of common sense, and nearly always is confronted with the problem of doing the best he can under circumstances that are far from ideal. Rarely does he find things arranged for his convenience or especially adapted to making his path smooth. The difficulties of getting public appropriations even for carrying on effectively the numerous departments and bureaus of government that already exist are known, and many of us have come in contact with the almost insurmountable obstacles of getting started anything new in the great administrative machine. Whether Mr. Freeman's ideas are ultimately realized or not, there will inevitably be a considerable period of time during which engineers will have to get along with what they have, and the speaker would refer to a phase of the subject suggested by some degree of contact during the last two or three years with what is going on in the great educational institutions that maintain departments of engineering. Here, the speaker believes, is a valuable potential for solving some of these problems. These college engineering departments have not only large and expensive plants but, what is more important, they have a large collection of youthful minds engaged in the acquisition of knowledge and experience and possessed of that keen curiosity which lends enthusiasm to investigating all unanswered questions.

The special local conditions on the St. Lawrence River, which arise from the heavy ice formations, have been mentioned. Similarly, some special local condition will be found almost everywhere, which is best studied on the

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\* Col., U. S. A., Cleveland, Ohio.

ground in that particular locality. Therefore, the speaker would suggest that pending the complete realization of some such plan as that advanced by Mr. Freeman, consideration be given to a more effective utilization, to this end, of the facilities that now exist, as by some systematic allotment or distribution of the problems that call for solution among the engineering laboratories already scattered widely over the country, with prompt co-ordination and concise report on results.

The reference to measures to prevent the encroachment of the Atlantic Ocean upon the Barnegat Lighthouse on the east coast of New Jersey, in connection with some early personal experiences in solving this specific problem, recalls to mind the old saying about the danger of defeating a new enterprise by the over-enthusiasm of its own friends. There are certain limits to laboratory experiments when dealing with great natural forces that must be recognized. This is evidently clearly appreciated by the proponent of a National engineering laboratory himself.

C. E. GRUNSKY,\* M. AM. SOC. C. E.—The speaker thinks the necessity of a hydraulic laboratory on a large scale has been well established by Mr. Freeman in his paper. The desirability of a program such as he has outlined should be recognized. Whether laboratory experiments will solve the problems of the lighthouse or of the Mississippi River, has no bearing on the question. There are other problems that should be studied in the laboratory, and the larger the scale on which a laboratory, as proposed, is built the better. It is beyond the reach of the individual university. The nation should provide the means for making large scale hydraulic experiments.

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\* Cons. Engr. (C. E. Grunsky Co.), San Francisco, Calif.

ground in that particular locality. Therefore, the speaker would suggest that pending the complete evaluation of some such plan as that advanced by Mr. Freeman consideration be given to a more effective utilization of the only of the facilities that now exist, namely, the existing laboratories. The solution that will be suggested is the construction of laboratories already scattered chiefly over the country with prompt coordination and control report on results.

The speaker in answer to queries, the improvement of the Atomic Energy Commission on the part of the Atomic Energy Commission, in connection with some of the present experiments in solving the specific problems has results in mind. The speaker would like to hear of the progress being made by the over-enthusiasm of its own groups. There are certain things to be done, and the speaker would like to hear of the progress being made by the over-enthusiasm of its own groups. There are certain things to be done, and the speaker would like to hear of the progress being made by the over-enthusiasm of its own groups.

O. R. Van Sledright, M. A., S. C. E. E. - The speaker thinks the necessity of a national laboratory on a large scale has been well established by the speaker in his paper. The benefits of a program such as he has outlined should be recognized. Whether laboratory experiments will solve the problems of the high power or of the Mississippi River or of the facilities on the question. There are some problems that should be studied in the laboratory, and the speaker would like to hear of the progress being made by the over-enthusiasm of its own groups. There are certain things to be done, and the speaker would like to hear of the progress being made by the over-enthusiasm of its own groups.

for making large scale hydroelectric experiments.

There have to be done for a hydroelectric plant. The speaker would like to hear of the progress being made by the over-enthusiasm of its own groups. There are certain things to be done, and the speaker would like to hear of the progress being made by the over-enthusiasm of its own groups.

